

# **Dynamic Haptic Feedback in Comparing Spatial Information**

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Simple haptic feedback has been used in mobile phones and other hand-held devices. In addition to auditory and visual feedback, haptic feedback would enhance the possibility of multi-modality and cross-modality.

In this study, a concept of dynamic haptic feedback is presented and predetermined spatial data was used to conduct an experiment. The goal of the experiment was to find out the most effective haptic feedback method on the palm where the experimented methods were pattern-based and frequency-based haptic feedback. The results showed that pattern-based response accuracy rate was 93% while frequency-based response accuracy rate was 78%. Recognition rates of different frequencies were substantially different while recognition rates of different patterns were closely similar. The result of the study can be further used in development of a new hand-held device which could display more accurate and precise haptic data, and would make haptic feedback through a hand-held mobile device more realistic.

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## 1. Introduction

The sense of touch is one of the customary interaction modality together with hearing, sight and smell in our everyday life. The sense of touch may act as a substitute for one of the other senses and thus, aspire to more active intelligent role in human-machine interaction. However, it has not been prominent until recently. Instead, visual and aural senses have been prevalent in human-machine interaction such as ringtones in mobile phones, alarms in wrist watches, beep sounds and error messages for wrong operations in calculators. In contrast, touch has been used only in a few cases; one example is vibrational cue as an alternative to audio signal for incoming calls or messages in mobile phones. The effect of touch is immediate and potent [Sally, 1984] and touch is used in social interaction by humans to communicate (dis)agreement, appreciation, interest, intent, understanding, affection, caring, support and comfort [Jones and Yarbrough, 1985] which means that humans are capable of understanding different information through touch. The science of touch (tactile) sensation, human perception and interaction are discussed in the research field of haptics [Raisamo et al., 2009]. The term haptic interaction may refer to the use of artificially produced haptic stimulations as a medium for communication between humans and machines or from one human to another human.

The mobile phone has become very common due to its portable and ubiquitous nature. This device is also considered as a private property for humans while, by nature, haptic interface through touch is a “private” medium [Luk et al., 2006]. Also, the future trends are moving to hand-held mobile devices. Therefore, the inclusion of haptic interaction in mobile phones or other mobile devices could provide potential benefits to users. However, as Raisamo et al. [2009] stated, for a long time haptic interaction has been a promise that has not been fully realized in everyday technology.

Processing speed in mobile phones advances with time. More applications are being built only for mobile phones and desktop applications are being adapted to mobile phones. At the same time, the evolution of Global Positioning System (GPS) has given freedom to monitor one’s current position and get guidance. While most mobile applications are developed to be used with aural and visual feedback, spatial data like GPS along with map representation can be too ample to present in a small display of mobile phone as displays can be very limited due to smaller size, lower resolution, fewer colors, and other factors [Chittaro, 2006]. Furthermore, the user can be situationally impaired, when engaged with other visual or aural feedback sources, for example, when driving a car. Some users can be permanently visually or aurally impaired due to blindness or deafness. For both of these user groups haptic feedback can be a good substitute because both can still use touch sensation and consequently tactile feedback can be used to provide information. Thus, the idea of presenting visual, textual

or aural spatial data with haptic feedback matches the conception of cross-modal interaction which allows the characteristics of one modality to be transformed into stimuli of different modality.

Aiming at introducing a haptic alternative to visual or aural representations of spatial data in mobile device, two types of haptic feedback are examined in this thesis. One of the research interests is analyzing the possibility of collaboration of spatial data. Spatial data may be known using GPS or RFID technology; however, in this experiment, any spatial data source from which spatial data can be obtained (for example, GPS, RFID) has not been defined and included. The other research interest is working with dynamic vibro-tactile feedback in which vibro-tactile feedback changes with distance and time. The aim of the research is to determine the effectiveness of haptic feedback methods.

For better understanding of the research topic, developing good knowledge of human physiology regarding touch and haptic sense is vital. Acknowledging this, in Chapter two we discuss the human somatosensory system focusing on the physiological perspective. This discussion is extended to the haptic perception process focusing on the perceptory view of somatosensory system which explains how tactile sensory perception intensifies, or gives guidance for the effective locations for generating appropriate haptic sensation on the somatosensory system.

In Chapter three, technologies for creating haptic feedback are introduced. There are many kinds of vibrating actuators and motors which are used to create haptic feedback. The discussion in this Chapter is significant for selecting appropriate technology for a device complying with the specific characteristics of haptic perception.

A lot of prior work has been carried out relating to the present research topic. Chapter four contains some of these research ideas in three groups - interpersonal communication, haptic patterns and navigation; all share the concept of the present research topic. A review of pedestrian navigation, map visualization and city exploration may be helpful to better understand how future concepts could be developed based on the current results.

The concept of dynamic haptic feedback is introduced in Chapter five: how spatial data presentation can be performed using dynamic haptic stimulation. The research questions of this research are also discussed in this Chapter.

An experiment with users was conducted. In Chapter six, the environments, the elements and the procedure of the experiment are described. This Chapter also includes the results of the experiment where user performance is analyzed from different perspectives.

In Chapter seven, the outcome of the experiment is further discussed by making conclusion, based on the major findings.

## 2. Physiology of Haptics

Human physiology focuses on many systems in the human body such as nervous system, musculoskeletal system, circulatory system, respiratory system, gastrointestinal system, integumentary system, urinary system, reproductive system, immune system, and endocrine system. In this Chapter, we focus on nervous system and specifically on the sense of touch. The somatosensory system is the component of central and peripheral nervous systems which receives and interprets sensory information such as pain, temperature, touch and proprioception through physical contact with skin. The system works with several different receptors such as thermoreceptors, nociceptors, mechanoreceptors, chemoreceptors and proprioceptors.

Human body is highly responsive to touch sensation (also referred to as tactile or cutaneous sensation). In fact, touch is approximately five times faster than vision [Geldard, 1960]. However, intensity of touch sensation, and speed with which information of touch reach the brain vary in different parts of the body. Skin is the heaviest organ in the human body but might not be the largest sensory organ ( $\sim 1.8\text{m}^2$  [Cholewiak and Collins, 1991]) because the surface areas of the gastrointestinal tract and the alveoli of the lungs exceed the surface area of the skin. Skin consists of three layers [Boron and Boulpaep, 2005]:

1. **Epidermis:** It is the outer layer of skin. The epidermis does not have blood vessels but has nerve endings. The main function of epidermis is to form a good protection against the outer world and waterproof the skin surface. Epidermis repairs and renews throughout whole life by producing new cells that are pushed to the outer layer. By the time new cells reach the outer layer of the epidermis, the cells are dead and cast off the slough.
2. **Dermis:** This layer is called true layer of skin which provides structural integrity, elasticity and resilience to skin. The layer is beneath the epidermis. It contains blood vessels, sensory touch receptors, sweat glands, smooth muscles and hair follicles. In this layer double row of papillae produces ridged pattern on finger tips, palms and soles of feet. Fingerprints and footprints keep skin from tearing and aid in gripping objects. Its sebaceous gland is responsible for creating wrinkles.
3. **Subcutaneous:** It is the deepest layer of the skin which is located under dermis. Subcutaneous layer contains mostly fat cells. It provides many direct protections from outside attack such as shock absorption, heat insulation. Loss of tissues in this layer leads to very visible wrinkles.

Epidermis and dermis are mainly the layers where mechanoreceptors are located. These receptors respond to mechanical stimulation such as pressure, stretching and vibration. Based on the speed of adaptation, skin receptors can be classified into two

categories, slowly adapting (SA) and rapidly adapting (RA). Slowly adapting receptors detect constant stimulus such as pressure and skin stretch while rapidly adapting receptors detect only short pulses such as initial contact and vibration.

Four kinds of mechanoreceptors in the skin are Merkel's disks, Meissner's corpuscle, Ruffini cylinder and Pacinian corpuscle:

1. **Merkel's disks:** Merkel's disks (Figure 1) detect sustained pressure and low-frequency vibrations. They can determine very fine texture changes, such as dots during reading Braille.
2. **Meissner's corpuscle:** Meissner's corpuscles (Figure 1) are sensitive to light touch. This receptor can perceive texture and these are most sensitive to stretching.
3. **Ruffini cylinder:** This receptor (Figure 2) located in deeper skin detects sustained pressure.
4. **Pacinian corpuscle:** Pacinian corpuscles (Figure 2) also lie deeper under the skin, and detect deep pressure and high frequency vibrations. These are responsive to a sharp poke, but not to a sustained push.

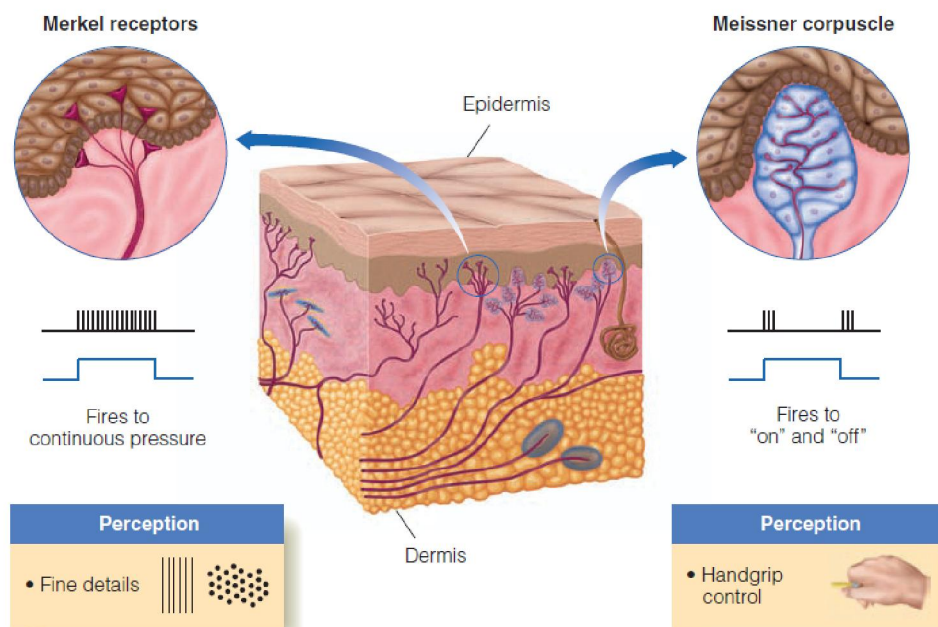


Figure 1: A cross section of glabrous skin, showing the layers of the skin and the structure, firing properties, and perceptions associated with the Merkel receptor and Meissner corpuscle [Goldstein, 2010]

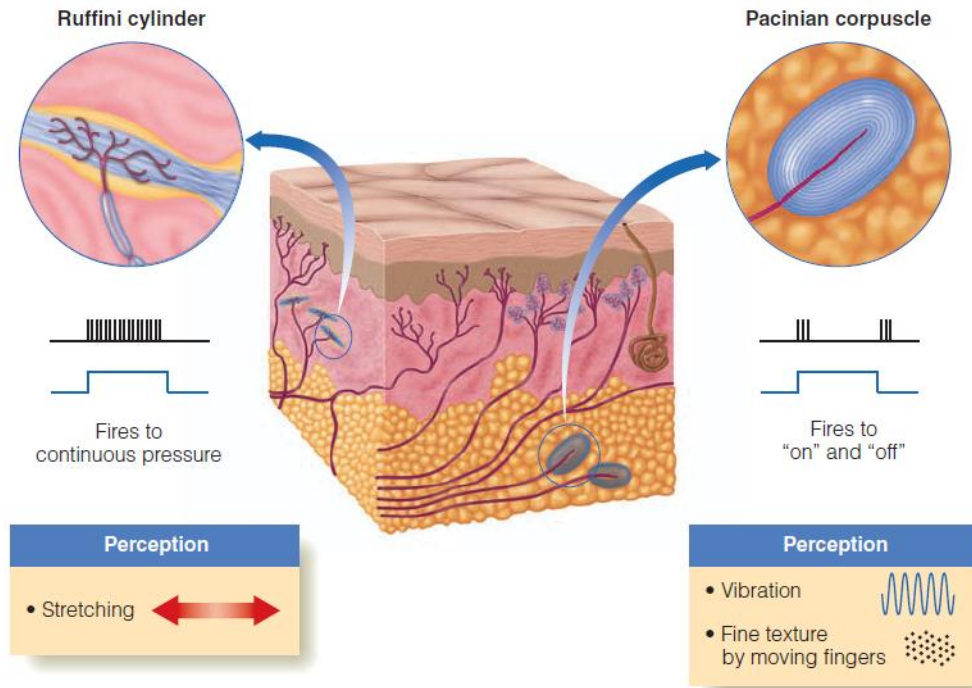


Figure 2: A cross section of glabrous skin, showing the structure, firing properties, and perceptions associated with the Ruffini cylinder and the Pacinian corpuscle [Goldstein, 2010]

Thus, these four kinds of mechanoreceptors have different functions. Table 1 shows different characteristics such as frequency ranges and adaptation rates of these mechanoreceptors.

Table 1: Characteristics of mechanoreceptors, adapted from Mazzone et al. [2003]

Mechano-receptor	Location	Rate of Adaptation	Receptive Field	Stimulus Frequency	Function
Merkel's Disks	Shallow	Slow SA-I	Small 12 mm <sup>2</sup>	0-10 Hz	Pressure; edges and intensity
Ruffini cylinder	Deep	Slow SA-II	Large 60 mm <sup>2</sup>	0-10 Hz	Directional skin stretch, Tension
Meissner's Corpuscles	Shallow	Rapid RA-I	Small 12 mm <sup>2</sup>	20-100 Hz	Local skin deformation, low frequency vibratory sensations
Pacinian Corpuscles	Deep	Rapid RA-II	Large 100 mm <sup>2</sup>	100 Hz-1 KHz	Non-localized high frequency vibration; tool use



Like cutaneous sensation, another somatic sense is proprioception which is often referred to as the seventh sense. Proprioception enables humans to control their limbs without directly looking at them. Information about joint angle, muscle length, and muscle tension are gathered and provided by proprioceptors. This information makes one aware of how fast and in which direction body limbs are moving and whether the movement is voluntarily or externally imposed. In addition, proprioceptors help perceiving limb's static position when movement stops by determining the static force which maintains limb position against the force of gravity. Proprioception works in conjunction with all other senses while it especially complements vestibular sensation and plays the key role in muscle memory.

Golgi and Ruffini endings (located in or near joints), Golgi tendon organs (located in tendons) and Muscle spindles (located in muscles) are described briefly below. Further, Table 2 shows comparative characteristics of these proprioceptors.

- **Golgi and Ruffini Ending:** These proprioceptors (Figure 3) are sensitive to tension or stretch on ligaments which are slowly adapting.
- **Golgi tendon organ:** This slowly adapting proprioceptor (Figure 3 and 4) in the tendon near the end of the muscle fiber is sensitive to changes in muscle tension.
- **Muscle Spindle:** These are the primary proprioceptors (Figure 3 and 4) in the muscle that are sensitive to changes in muscle length. These are also slowly adapting receptor.

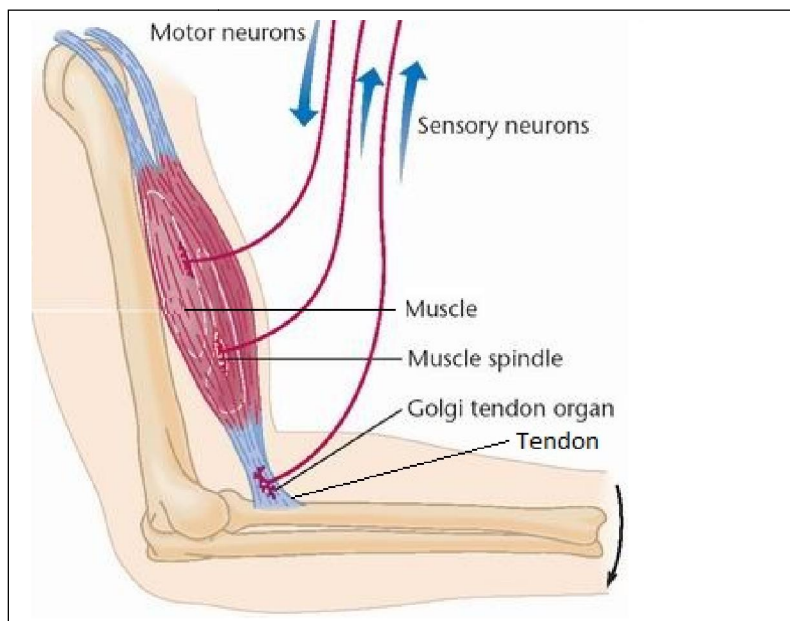


Figure 3: Proprioceptor [MedicaLook, 2012]

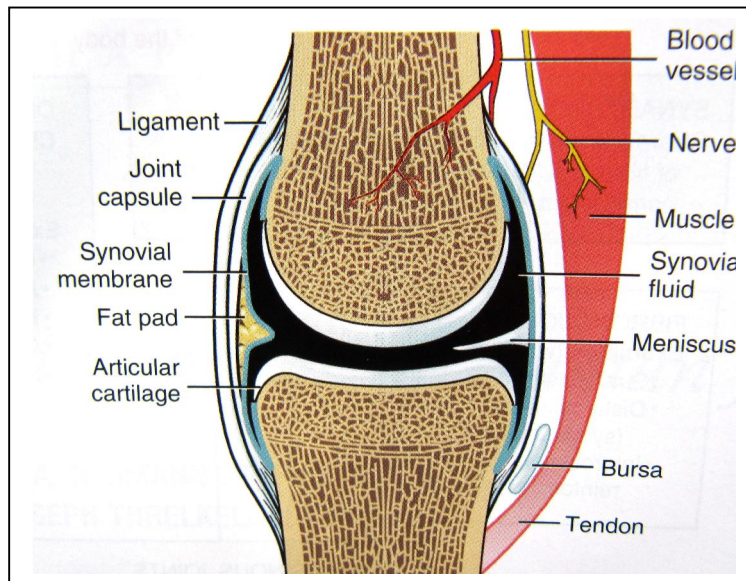


Figure 4: Proprioceptor [Neumann, 2002]

Table 2: Characteristics of proprioceptors, adapted from Mazzone et al. [2003]

Proprioceptor	Location	Stimulation Objective (physical parameters to be sensed)	Stimulation Type
Golgi Endings	Joint ligaments	<ul style="list-style-type: none"> <li>Joint movement at end range of motion</li> <li>Extreme flexion/extension</li> </ul>	<ul style="list-style-type: none"> <li>Joint tension at extreme positions</li> </ul>
Ruffini Endings	Joint capsules	<ul style="list-style-type: none"> <li>Joint movement, particularly at end range of motion</li> <li>Static and dynamic</li> </ul>	<ul style="list-style-type: none"> <li>Capsule stretch</li> </ul>
Golgi Tendon Organs	Tendons	<ul style="list-style-type: none"> <li>Active position sense</li> <li>Link to limb position Force</li> </ul>	<ul style="list-style-type: none"> <li>Muscle tension and force</li> </ul>
Muscle Spindles	Muscles	<ul style="list-style-type: none"> <li>Active movement of muscles</li> <li>Conscious experience of body movement and position</li> <li>Weight supported by limb</li> </ul>	<ul style="list-style-type: none"> <li>Muscle stretch/rate of change</li> <li>Vibration</li> </ul>

In summary, the two somatic senses (cutaneous sensation and proprioception) discussed above together create haptic perception. There are particular receptors namely mechanoreceptors, among many other receptors which are mainly responsible for

receiving signals of cutaneous stimulation. Merkel's disks, Ruffini cylinders, Meissner's Corpuscles and Pacinian corpuscles are those mechanoreceptors which respond to the various stimulations from environment. Again, proprioceptors such as Golgi and Ruffini endings, Golgi tendon organs and Muscle spindles indicate position of limbs. Among different mechanoreceptors in the body, Meissner's Corpuscles and Pacinian corpuscles can play important role for rapid change of understanding during our perception through touch by palm. For understanding the concept of this thesis, Meissner's Corpuscles and Pacinian corpuscles would be the key mechanoreceptors.

### 3. Haptic Perception and Technology

In the case of asking a person, which sense she or he would rather lose, many would pick touch. They may assume that the absence of this sense would not influence daily life, perhaps because of their lack of experiencing this particular kind of sensory disability. However, even with proper training, the movement of body parts would be difficult and completion of day-to-day simple tasks would be greatly hindered. In the next Section, we discuss haptic perception and its scope in human computer interaction. The following two Sections contain the concept of haptic perception and framework of haptic interface to better understand the properties of haptics. In the last Section, haptic technologies are discussed.

#### 3.1 Haptic Perception

Haptic perception refers to the recognition process of an object through touch when sensory information is derived from both cutaneous receptors and proprioceptors. The words “haptic” and “tactile” are in many texts used as synonyms. However, semantically “haptic” is different from “tactile”; “tactile” refers to cutaneous inputs alone and “haptic” refers to condition involving both cutaneous and kinaesthetic inputs [Loomis et al., 1986]. Visualization is vital when “exploring data and information in such a way as to gain understanding and insight into data” [Brodie et al., 1992]. Vision tells us about form more rapidly than touch [Davidson et al., 1974] and it is usually more accurate than touch when forms are two dimensional and time is limited [Loomis et al., 1981]. Furthermore, vision is dominant over haptics in shape detection when the two senses are in conflict and vision is clear and foveal [Rock and Victor, 1964]. However, when vision is blurred, haptics can add one more dimension for sensory perception [Heller, 1983]. Moreover, for judgments of surface texture [Heller, 1982], haptics can be more effective than the other senses. Thus, haptic information is important in determining shape, weight, surface texture and temperature.

Haptic perception is usually related to active touch (conscious touch with purpose of exploring an object), while tactile perception according to Gibson [1962] is more related to passive touch. Further, various parts of touch organ are not equally sensitive to the spatial separation of two simultaneous points of contact [Weber, 1996; Weinstein, 1968]. Also, touch sensitivity may differ by gender and age. Spatial acuity of haptic perception refers to sensitivity of space amidst sensation points on the skin. Two point discrimination, gap detection, grating orientation and letter recognition [Johnson and Phillips, 1981] are some available measures to evaluate spatial acuity. However, two point discrimination is not recognised as a spatial acuity [Craig and Johnson, 2000] because “the distance by which the [two] objects [placed on the skin] must be separated to be experienced as two objects rather than one” [Roediger et al., 1996]. Craig and Johnson [2000] accepted gap detection, grating orientation and letter recognition as the correct measure of spatial acuity. Gap detection is sensitivity of edges in a gap or

sensitivity of solid state of an edge [Johnson and Phillips, 1981] while change in gap width changes threshold size. Grating orientation is a measurement with tactile gratings which contain alternating grooves and ridges [Legge et al., 2008]; a change in grooves and ridges makes a change in threshold size. Further, letter recognition is the concept of reading letters or characters by using touch.

Temporal acuity for touch is the difference between two consecutive stimuli having approximate time difference of 5ms. Due to difference in age temporal acuity may differ. In an experiment, Craig et al. [2010] found that the older subject requires two to five times of temporal separation required by the younger subject.

Using three measures of sensitivity (i.e., pressure sensitivity, two-point discrimination and point localization\*) Weinstein [1968] measured touch sensitivity in men and women. In women pressure sensitivity threshold is lower than in men and pressure sensitivity on both the sides (i.e. left and right) of the body is generally same. In human body, the forehead (face), trunk, fingers are most sensitive to pressure. The face can sense the smallest pressure threshold which is about 5 mg in weight (equivalent to weight of a dropping wing of a fly from 3 cm onto the skin). Further, fingers, forehead and feet are most sensitive for two-point discrimination and the fingers, the forehead, and hallux are most sensitive for point localization. *Vibration sensitivity* is another measure of tactile acuity. Goff et al. [1965] found that gender difference does not impact much for vibration at 100cps (cycles per second), but at higher frequency than 100cps. For instance, for the index finger men have lower vibratory thresholds than women. However, human sensitivity for vibration increases about above 100 Hz and decreases above 320 Hz while 250 Hz is considered as the optimum.

Haptic perception is always a combination between bottom-up or stimulus-driven and top-down attention or cognitive processes [Peltier et al., 2007; Deshpande et al., 1991]. The perception can also be affected by difficulty level of the task and amount of cognitive load. Letter discrimination, for instance, will be more difficult in sense of cognitive load comparing to simple spatial or temporal discrimination tasks. Further, touch perception along with haptic perception can be faultier at old age. However, training and expertise on tactile and haptic experience can counteract age-related decline in the performance of tactile and haptic perception. In a real analysis of tactile acuity on the fingertip of blind braille readers any age-related decline was not found [Legge et al., 2008]. In addition, on specification of average performance of sighted subjects, Goldreich and Kanics [2006] outlined that blind persons have superior tactile acuity to age-matched persons.

\*Point localization is the ability to locate the point on the skin that has been touched.

### 3.2 Framework for Haptic Interfaces

A haptic interface generates suitable haptic feedback using mechanical stimulation. Using a haptic interface a human can perceive information about the environment by receiving and analyzing the stimulation from the environment and can also interact with the environment. Thus, haptic interface can be used both for giving input and displaying output. For developing an effective haptic interface a holistic framework can be used; a framework provides a skeletal structure and necessary foundation for designing the device. Because of wide variation in quantitative measurement of human factors, Tan et al. [1994] describe a framework for designing a force reflecting haptic device. In their research, they discussed the framework by defining different attributes so that haptic interface could know which attributes to be displayed for haptic sensation. In this discussion, they considered four major perceptual issues and three manual performance issues in haptic interaction; the perceptual issues were 1) force sensing under quasi-static and dynamic conditions, 2) pressure perception 3) position sensing resolution, and 4) the level of stiffness required for rigidity simulation. The manual issues were 1) the maximum forces human can produce, 2) the precision with which human can control a force, and 3) the control bandwidth of force.

Nesbitt [2005] presented a framework on multisensory design space named as MS-Taxonomy for explaining the difference between haptic, visual and audio display and collaborating design space for different sensory interaction. The framework includes the general knowledge of design and using the framework a haptic interface designer can compare designs that use different haptic, sound and visual properties. The taxonomy is based on three high-level information metaphors which are spatial metaphor, direct metaphor and temporal metaphor.

Spatial metaphor involves perceiving visual, audio and haptic stimuli that are organized and interpreted in space. Spatial metaphor employs a design space. A design space is an abstract form of environment which defines a presentation region in space (called display space and shown in Figure 5), and arrangement of components in this display space (called spatial structure and shown in Figure 6) and properties of this spatial structure (called spatial properties and shown in Figure 7). The spatial measurement of haptics is common and familiar. Thus, spatial properties in haptic sense can be defined explicitly. Spatial properties of visual sense are also explicit while the same of auditory sense are not.

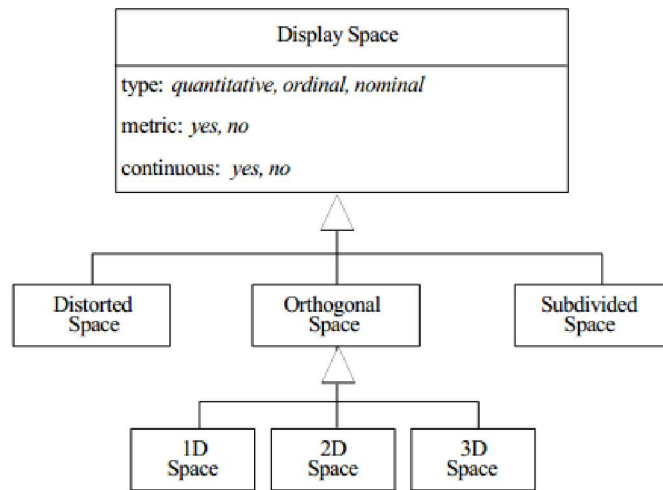


Figure 5: Types of display space [Nesbitt, 2005]

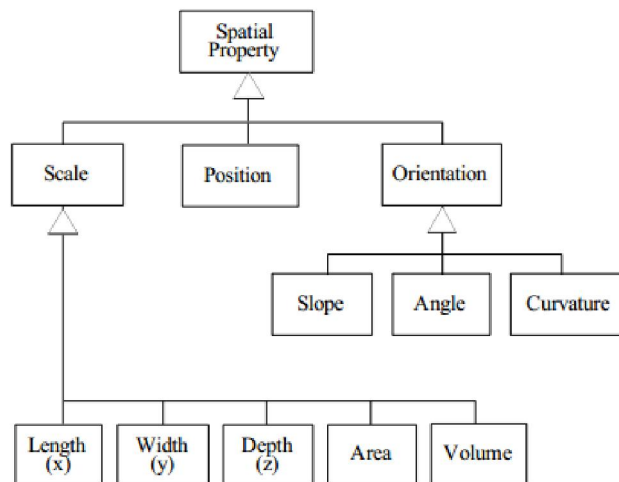


Figure 6: Types of spatial properties [Nesbitt, 2005]

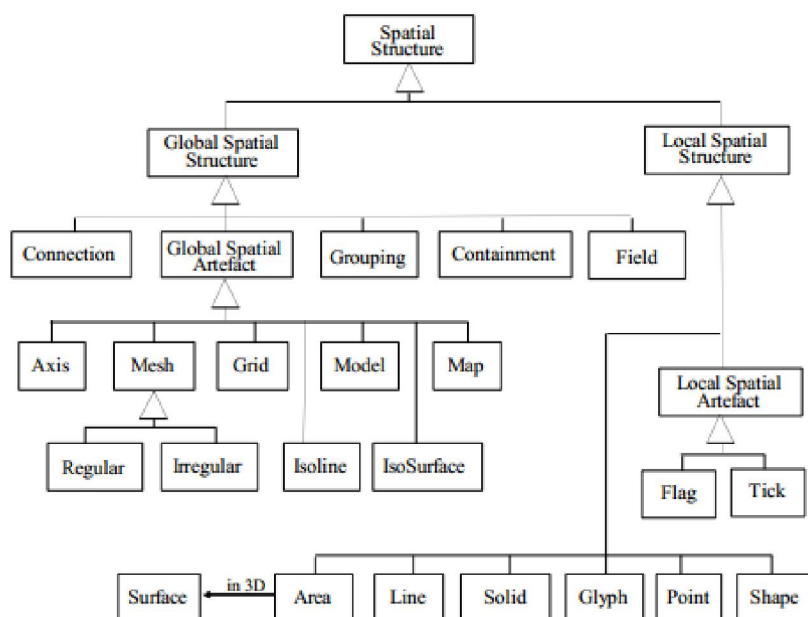


Figure 7: Types of spatial structure [Nesbitt, 2005]

Direct metaphor involves perceiving properties of visual, auditory and haptic stimuli in immediate vicinity directly through the respective sensory receptors. Direct metaphor is defined by spatial structure and the properties of this spatial structure (called direct properties). Direct properties for different sensory organs may not be equivalent and further, accuracy of judgment may vary for individual users. Direct haptic metaphor establishes direct mapping between physical attributes of data and perceived properties of the haptic sense. Figures 8 and 9 show direct haptic properties associated with tactile and kinesthetic stimuli.

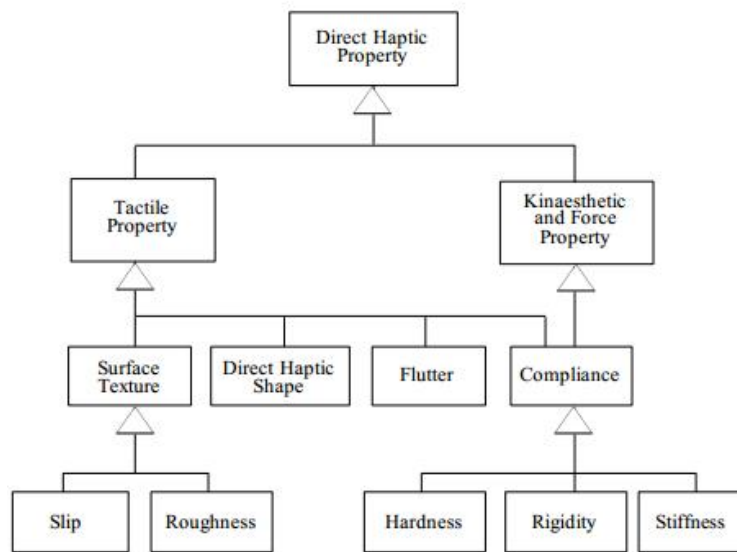


Figure 8: Direct haptic properties associated with tactile [Nesbitt, 2005]

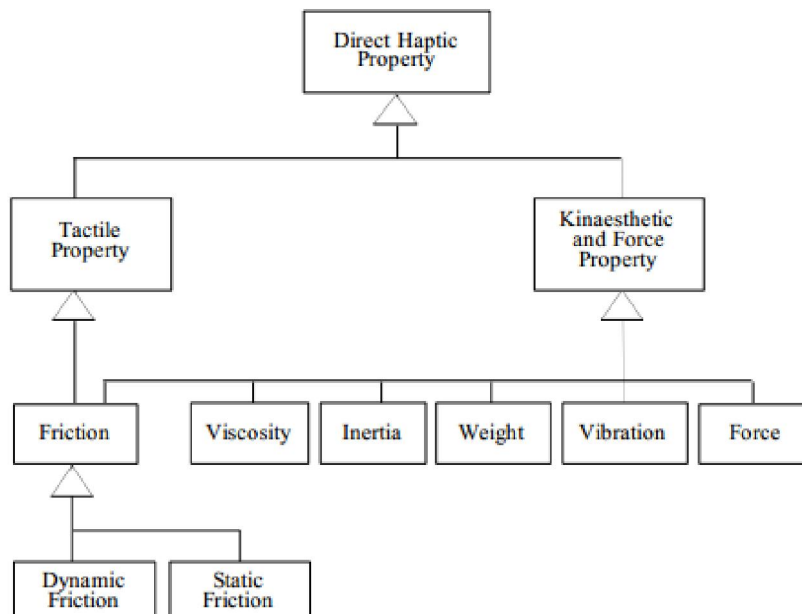


Figure 9: Direct haptic properties associated with kinesthetic and force stimuli [Nesbitt, 2005]



Temporal metaphor concerns with perceiving changes of visual, audio and haptic stimuli over time. Simultaneous change in temporal metaphor occurs with the change in spatial metaphor and direct metaphor (Figure 10). Temporal metaphor is described with the concept of the display time, an event and the temporal structure. The display time is a temporal reference for the stimuli or data to be displayed. Changing display time can increase or decrease the display rate of the presented data. An event contains two properties, event time and event duration, which receive temporal reference from display time (Figure 11). Temporal structure includes rate of events, rhythm of events and the variation of events. To compare events perceived in temporal metaphor past event properties need to be saved or memorized for reference. Temporal haptic metaphor is composed of a number of events that have temporal structure of haptic metaphor. Spatial haptic metaphor observes the organization and interpretation of haptic stimuli in space, direct haptic metaphor concerns with the perception of haptic properties and temporal haptic metaphor is involved with understanding how haptic stimuli change over time.

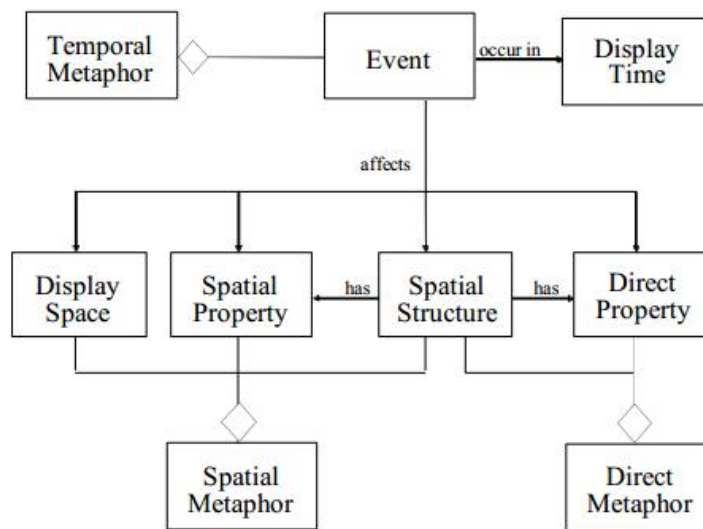


Figure 10: Temporal metaphors are dependent on the perception of time and are characterized by events that modify spatial and direct properties [Nesbitt, 2005]

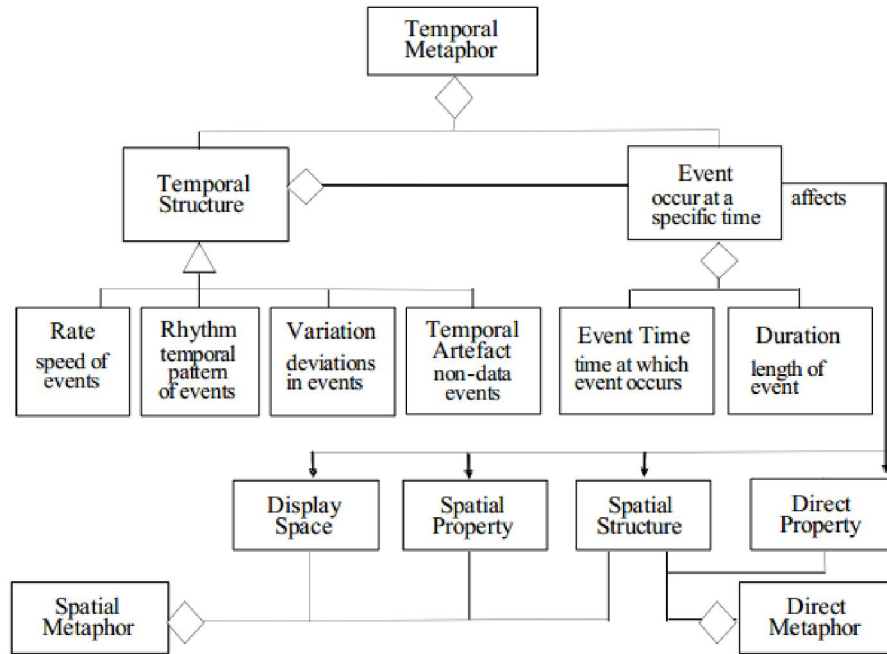


Figure 11: Temporal metaphors are often composed of a number of events that have some temporal structure. [Nesbitt, 2005]

In addition to this framework, Nesbitt [2005] described a meta-process in order to design process of perception with a prototype device (Figure 12).

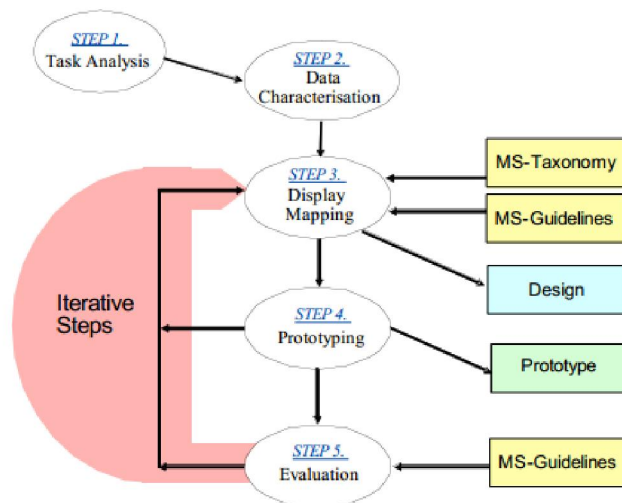


Figure 12: Steps of the multi-sensory design process [Nesbitt, 2005]

### 3.3 Haptic Feedback Technologies

The haptic feedback is created by an actuator which produces some kind of haptic stimulation like force feedback on the body, or produces touch stimulation on the skin [Hasser and Daniels, 1996]. Actuators convert energy (mostly electrical energy) into motion. Actuators can, for example, create motion in one direction, in a circular motion or in opposite directions at regular intervals. Vibrating motors, linear motors, solenoids, piezoelectric actuators and pneumatic systems are some examples of actuators which are used to create tactile stimulation with different methods such as skin deformation, vibration, electric stimulation, skin stretch, friction (micro skin-stretch) and temperature changes. Actuators can be configured using either a single element or multiple elements in an array or matrix.

**Vibrating motors:** The vibrating motor provides relatively small amplitude linear or rotatory vibration. This motor can be used alone or in an array arrangement. Vibration motors have existed since the 1950s; however, in the 1990s they received more attention when added to mobile phones. Vibrating motors create vibration most commonly using DC motors that are based on eccentric rotating masses. When DC motor rotates an off-center spinning mass it works similarly to an imbalanced tire in a car making the steering wheel shake and creates vibration. However, vibrating motor is not perfectly accurate in quality in controlling vibration, though these are inexpensive. These are used in mobile phones, pagers and game controllers. Vibrating motors are good in considering lower power consumption and simple manufacturing technology and bad in the level of expressive feedback.

**Voice coil motors:** In voice coil motors current is propagated through movable coil which create a magnetic field and that interact with the permanent magnet. Thus vibrations are created by switching the current off and on repeatedly. In voice coil based motors frequency and amplitude of vibration can be controlled in a better way than in eccentric rotating mass based motors such as vibrating motors. However, it requires a relatively large input electrical energy and has low response and produces low generative forces.

**Linear actuators:** The linear actuator creates motion in one direction using, for example, an actuated pin that is in direct contact with the surface of the body. These actuators are built using mechanical elements such as a screw that transforms rotatory motion into linear motion. The actuator built on simple technology actuates relatively fast. The vibrational properties can be controlled accurately. However, tight packing of the mechanical elements can be difficult. In Braille displays and mice with tactile arrays, the usage of linear motor is effective.

**Solenoids:** The solenoid is a helical coil enfolding a pin. Solenoids use electromagnetic current to convert electrical energy to mechanical energy which allows the pin to move forward or backward. Solenoids are used in multimodal mice and haptic pens.

**Piezoelectric actuators:** Some fine ceramics called piezoelectric materials, consisting of Lead (Pb), zirconium (Zr) and titanium (Ti) produce an electric charge when a mechanical vibration or shock is applied to the material. Further it exhibits a reverse effect by creating mechanical vibration or shock when electricity is applied. That is why these materials are used for producing vibration feedback. Multiple layers can be used to amplify the effect. Piezoelectric actuators have a number of potential advantages. They are small in size and more compact comparing with the other kinds of actuators. Also, these actuators can provide a greater force and rapid start and stop. Further, because these actuators do not use electro-magnetic field, other actuators and sensors can work effectively besides piezoelectric actuators. However, piezoelectric actuators have some disadvantages including necessity of high voltage and adjustment of displacement.

**Pneumatic actuators:** Pneumatic actuators work by controlling air pressure on the skin. Pneumatic actuators use compressed air acting on a piston inside a cylinder to move a load along a linear path. It can generate vibration frequencies between 20 Hz and 300 Hz. Pneumatic systems require air compressor and, therefore, these actuators may be large in size and not portable; however, with the help of tubing it is possible to keep the weighted part of the system at a distance from the point of application. It can mimic skin slip but not sharp edges or discontinuities.

**Other technologies:** There are also many other technologies for creating vibrational feedback and touch sensation on skin. Shape-memory alloy creates vibration on skin by utilizing the property of expansion and contraction of metal with heat. Skin-stretch is an alternative method to vibrational stimulation which applies force to skin so that the force could be felt as stretching. Also, electro-tactile stimulation is used for haptic sensation. This kind of stimulation is so strong that it can be recognized easily; however, its use is limited to research prototypes and rehabilitation processes. Acoustic radiation can create weak pressure which can generate transient vibratory stimulation. Furthermore, when current is applied on electro-rheological fluid, this liquid changes into semi-solid and creates the feeling of resistive surface. Thus, there are many technologies for creating haptic sensation on the skin and newer technologies are gaining more control over vibration properties like rapid response time and vibration accuracy.

### **3.4 Summary**

In this Chapter, the haptic perception was discussed and the properties of the haptic perception were analyzed. Two frameworks were described which provide concept of designing a haptic interface. Thus, the discussion in this chapter provides the concept of haptic perception created from stimulation by an object or haptics. Furthermore, introducing haptic feedback technologies assists in understanding how technology can be used appropriately to address the properties of haptics. The concept of haptic property and manufacturing mechanism of haptics would assist for arranging necessary elements and environment in the experiment.

## 4. Mobile Applications using Haptics

The objective of this Chapter is to present the existing research displaying spatial data using the haptic feedback. Applications are discussed from three different perspectives: interpersonal communication, haptic patterns and navigation. Interpersonal communication is one of the most commonly used tasks where haptics acts in spontaneous manner. With very little change in tactile pattern, the meaning and perception of touch can be distinctive. Therefore, the review is focused on how the delicacy of touch sensitivity is addressed in haptic interfaces. Further, there is a review on usage of haptics in navigation.

### 4.1 Haptics in Interpersonal Communication

Touch implies closeness and intimacy because through touch we may convey our intimate feelings and emotions to another person next to us; touch alleviates even physical suffering [Edvardsson et al., 2003] which is a common phenomenon during nursing of patients. Several tactile communication prototype devices have been realized that are used, for example, for textual and auditory interaction [Rantala et al., 2011b]. In this Section, textual and auditory interaction based prototype devices and their use in tactile communication are discussed.

Haptic effect [Rovers and Essen, 2004], in Instant Messaging (IM) communication, was used to address realistic user-need of sharing emoticons for enhancing audio/visual information content. In this paper, a conception of haptic IM framework was presented where haptic feedback and hapticon (or haptic icon, brief programmed forces applied to user through a haptic interface [Csapo and Baranyi, 2011]) (Figure 13) support text messages in the context of instant messaging to resolve ambiguity arising during chatting. In this framework, they propose a special language, consisting of signals, to convey haptic messages to the counterpart user that can be used for conveying secret messages using secret tags and gestures. They implemented the proposed system by using commercial force feedback joysticks and touch pads as well as two custom made IO devices (a finger touchpad input and a vibration pencil output) (Figure 14). They did not arrange any usability test to monitor the performance of users using the haptic effects or present the pattern of haptic effects exerted to user.













Icon	Emoticon	Meaning	Hapticon
	: )	regular smile	
	: D	big smile	
	: (	sad face	
	; -)	wink	
	( k)	kiss	
	: \$	embarrassed	

Figure 13: Some emoticons and proposed hapticons [Rovers and Essen, 2004]

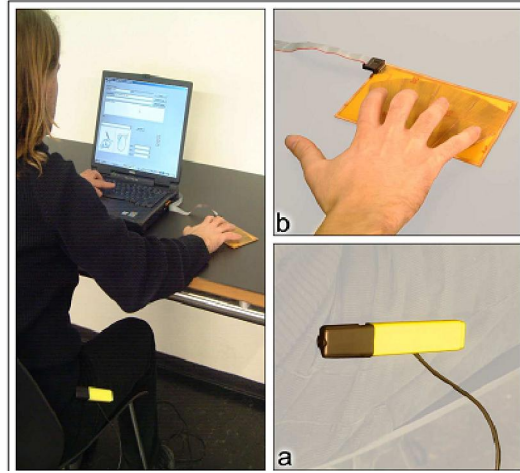


Figure 14: Examples of custom-made devices:

(a) vibration device and (b) resistance based touch pad [Rovers and Essen, 2004]

Shake2Talk [Brown and Williamson, 2007] is a prototype that uses haptic feedback to enrich auditory interaction. This innovative system was developed for embedding touch sensation to audio messages in remote communication. Tactile sensation for a message can be selected from two alternatives which are simple gesture (such as tap, twist, flick or stroke) (Table 3) and a series of menus. Table 4 describes a possible scenario with selected combination of sound and gestures. Because audio message is not private, to impose privacy in audio message, researchers chose to make allegorical and non-speech sound such as tapping, pouring of liquid and snoring as output. The aim of making this kind of sound is that people such as couples, close friends or family members could perceive the sound privately. In prototype device, a SHAKE device from SAMH Engineering is attached to the back of a smart phone. The SHAKE device used different sensors such as accelerometers, gyroscopes and capacitive sensors to recognize gestures, and it also generates vibro-tactile output through its eccentric pager motor. No evaluation of the prototype was reported. However, the researchers raised some questions to be addressed in future the evaluation process, for example, format of audio-tactile messages and context of delivering message.

Table 3. Four types of gesture used in ShakeTalk  
[Brown and Williamson, 2007]

<b>Gesture</b>	<b>Recognition</b>
<b>Stroke:</b> User slides a finger from one capacitive sensor to the other in a “stroking” motion.	Recognition is performed by a simple finite state machine, based on thresholds on the capacitive sensor values and their derivatives. The machine accepts sequences of the form 1-down-1-up-2-down-2, within a certain timeout. On reaching the final state, the gesture event is triggered.
<b>Tap:</b> User taps a finger on a single capacitive sensor.	The tap recognizer also uses a state machine, with state changes triggered by threshold crossings from a single capacitive sensor. When the capacitive sensor is quickly activated and deactivated, the appropriate event is generated.
<b>Flick:</b> User moves the device forwards, then backwards, in a quick, sharp motion, like cracking a whip.	Flicking is sensed by accelerometers. The flick recognizer uses a physical model of a point mass anchored via a spring inside a sphere with a simulated viscous fluid. Rapid motions overcome the attraction of the spring and the damping effect of the fluid to strike the wall of the sphere, triggering the gesture event.
<b>Twist:</b> The user turns the device through a 180 degree rotation.	Twisting is sensed by gyroscopes, using a leaky integrator which operates on a single angular axis. The gesture event is triggered when the integrator output crosses a threshold.

Table 4. Possible scenarios comprising of corresponding sounds and gestures  
[Brown and Williamson, 2007]

<b>Scenario</b>	<b>Sound</b>	<b>Gesture</b>
“Call when you can”	Gentle tapping	Tap
“I need to talk to you”	Tapping on a wine glass	Tap
“Call me now (angry)”	Banging on metal	Tap
“Fancy a drink?”	Beer pouring	Twist
“Relax!”	Wine pouring	Twist
“Home Safely”	Key in lock	Twist
“Thinking of you”	Regular heartbeat	Stroke (regular speed)
“I’m nervous”	Racing heartbeat	Stroke (fast)
“I’m bored”	Snore	Stroke
“happy”	Cat purring	Stroke
“I’m rushing”	Fast footsteps	Twist back and forth
“I’ve put the dinner on”	Rattling of pots and pans	Twist back and forth
“Angry”	Plates smashing	Flick
“Playful slap”	Slap	Flick
“Hurry Up”	Whip crack	Flick



ComTouch [Chang et al., 2002] is another prototype device working with audio and tactile feedback. Unlike Shake2Talk, ComTouch complements voice interaction to enhance interpersonal communication. It is a handheld device which transforms finger pressure into vibration in bidirectional and asynchronous manner. In the system, input is generated with fingertip which in turn generates feedback with vibration on the middle part of same finger (Figure 15). The actual output is provided to the base of receiving users' finger. The proposed system was derived after experimenting with a series of exploratory form factors which consists of two hand-shaped pads (Figure 16). The pads mapped touch to vibration using force sensing resistors (FSR) for measuring pressure ranging from 0.45psi (light squeeze) to 150psi (hard squeeze) and speaker actuator (V1220 model from AudioLogic Engineering) for presenting tactile feedback.

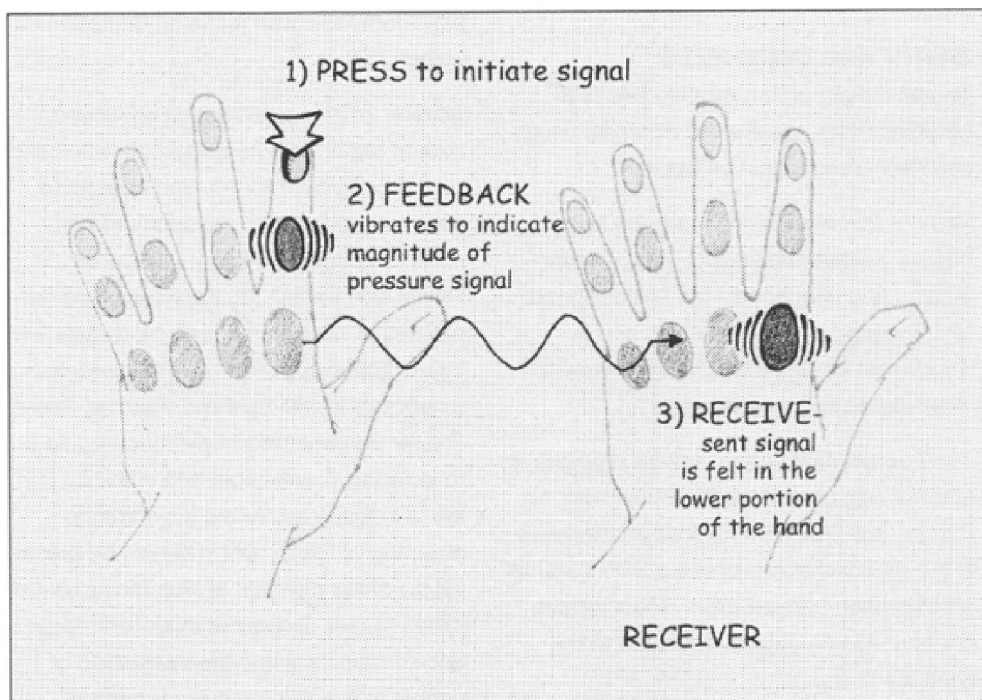


Figure 15: ComTouch touch-to-vibration mapping [Chang et al., 2002]

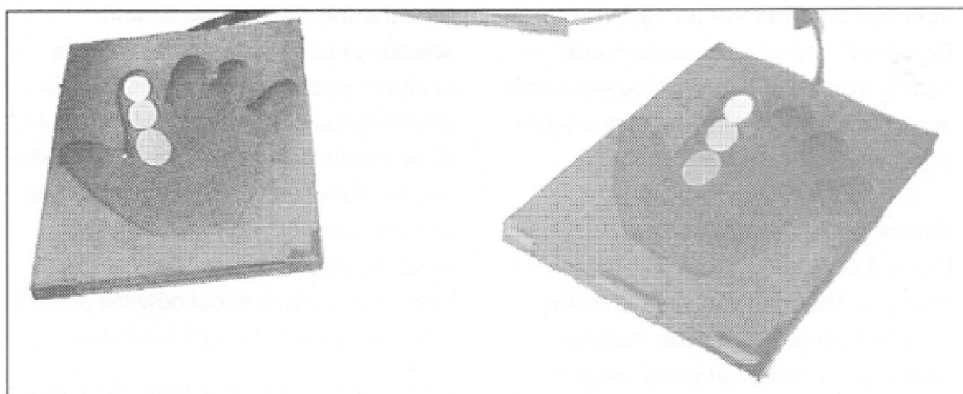


Figure 16: ComTouch preliminary implementation. One finger of vibro-tactile communication is conveyed between two pads. [Chang et al., 2002]

With the system, the researchers arranged two experiments; first experiment is chatting where participants used audio and tactile channel without specified instruction, and second one is Desert Survival Problem (DSP), a negotiation skill task with limited audio channel and without using eye or visual contact. From these experiments they found that the device was used for three tactile gestures that were expression, turn-taking and mimicry. At least one of three tactile gestures was used by 83% of the subjects. In second task, for negotiation purpose participants used numbering scheme and yes-no binary reply (Figure 17). The participants suggested that the system may be more successful for communicating between familiar persons than between strangers. Furthermore, participants suggested more information channels by engaging multiple fingers instead of only one finger.

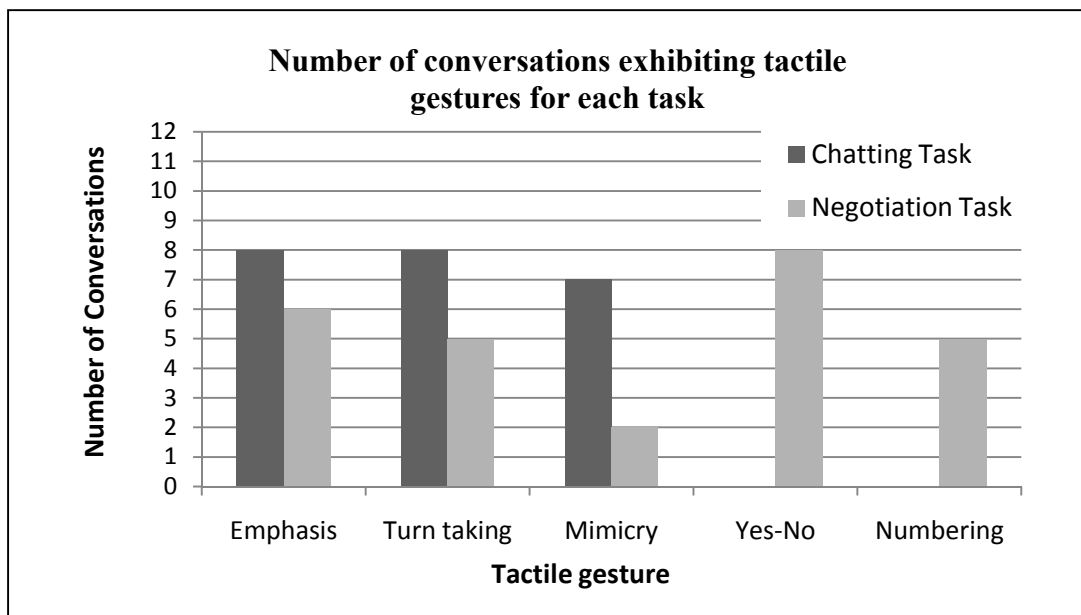


Figure 17: Number of conversations exhibiting tactile gestures  
[Chang at el., 2002]

Three research papers are discussed above to analyze the usage of haptics in interpersonal communication. Haptic effect [Rovers and Essen, 2004] is the first paper which focuses on research of composing haptic feedback. This feedback, known as hapticon, is similar to conception of emoticon in the case of visual feedback, and used for enhancing audio or visual message. In the second paper, Shake2Talk [Brown and Williamson, 2007] is discussed where users communicate using different pre-determined haptic patterns. The third paper discussed in this Section, ComTouch [Chang at el., 2002] uses haptic feedback for augmenting audio conversation. In these papers, researchers introduce their prototype devices to create proper haptic feedback; however, the accurate recognition of haptic feedback might be difficult if users in prior are not accustomed to this feedback.

## 4.2 Haptic Patterns in Mobile Applications

In designing new prototypes for tactile interaction, designing naturalistic patterns for tactile feedback, which can be easily distinguishable and perceivable, is a major research issue. The goal of the tactile pattern display is to portray haptic effects to a user through modulation of the shear forces acting on the finger [Winfield et al., 2007]. Brewster and Brown [2004] clarified that frequency, amplitude, waveform, duration, rhythm and body location are the parameters used in producing different patterns for tactile feedback. In this part of the paper, some research conceptions on displaying haptic patterns are discussed.

In social interaction, knowing interpersonal distance is most important. However, visually impaired people do not have access to most or all of the non-verbal cues with other persons during social interaction and due to the impairment inadequate social skills may develop. McDaniel et al. [2009] describes a system which conveys location information to a visually impaired person about a person standing in front of him. Displaying different tactile rhythms, this proposed system informed the direction of the standing person relative to the user and also, the interpersonal distance between them. For easy identification, based upon some pilot studies, the researchers developed four rhythms - each of 10 seconds in length. These rhythms are based on 50 ms vibro-tactile pulses separated by pauses of 50 ms, 250 ms, 500 ms or 1200 ms (Figure 18) which were mapped to interpersonal distances of intimate, personal (close phase), personal (far phase) and social (close phase) space, respectively. With these four tactile rhythms, researchers conducted an experiment to study participants' performance in identifying the rhythms. For the experiment they used an elastic vibro-tactile belt where seven actuators were used in equidistance from each other and placed in semicircle from left side to right side keeping middle one on navel. As an actuator, a pancake motor with diameter of 10 mm and length of 3.4 mm was used which operated at 170 Hz. To identify the communicator and his location a wearable video camera was used. To extract the information collected by a camera, computer vision algorithms were used. Participants taking part in the experiment wore the vibro-tactile belt and could sense the rhythmic vibration to interpret the interpersonal distance from another person and to determine the other person's direction relative to participant's position. Then, haptic icons were presented to the subject and in turn the subjects responded accordingly. In the experiment, the overall recognition accuracy for location was 95%, for rhythm 91.7% and for both 87%. The participants felt that they could accurately detect the haptic icons although identifying direction was easier than distance.

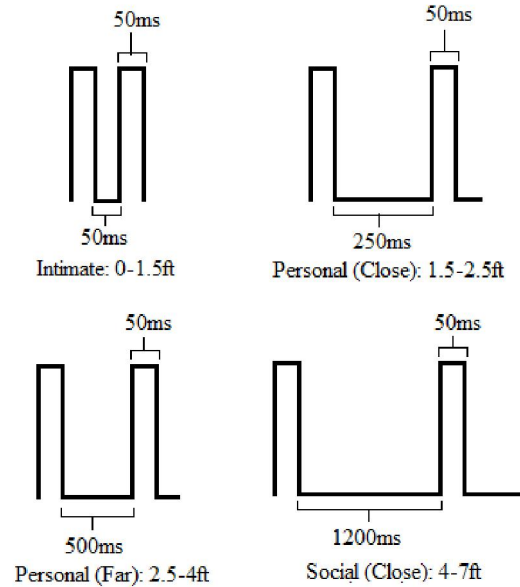


Figure 18: The on/off timing values of the four tactile rhythm designs, and corresponding distances, used in the experiment [McDaniel et al., 2009]

Finding difficulties in differentiating closely-spaced high frequency vibro-tactile actuators, Rantala et al. [2011a] introduced a low frequency multi-actuator tactile device for presenting spatial tactile messages. Four linear DC motors (LVCM-013-013-02 from MotiCont) (Figure 19) were employed in this device to present four main directions of movement that were left, right, forward and backward. Using these vibro-tactile cues, diamond and square shaped patterns (Table 5 and Table 6) were displayed to examine recognition accuracy of vibro-tactile feedback. In the experiment participants sensed and tried to recognize these predefined stimuli. The experiment showed that mean response accuracies for positional, linear and circular patterns with the diamond configuration were 97.9, 94.7, and 89.3%, respectively while with square configuration the corresponding accuracies were 99.6, 98.2, and 91.1%.

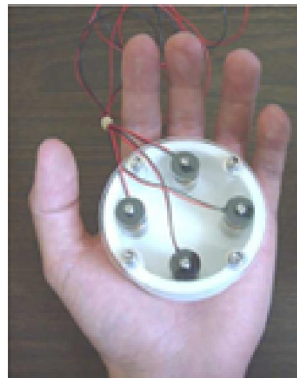


Figure 19: Prototype device [Rantala et al., 2011a]

Table 5. Patterns for the diamond configuration [Rantala et al., 2011a]

Positional				
Linear				
Circular				

Table 6. Patterns for the square configuration [Rantala et al., 2011a]

Positional				
Linear				
Circular				

Three patterns of moving, squeezing and stroking (Figure 20) were introduced to analyze preferred methods to create haptic messages using a hand-held haptic device [Rantala et al., 2011b]. The device was built for both input and output.



Figure 20: Input method of (a) moving, (b) squeezing and (c) stroking [Rantala et al., 2011b]

To integrate output, there were one C2 linear vibro-tactile voice coil actuator (of diameter 3.05cm) (Figure 21, dashed circle) and four Minebea Linear Vibration Motor actuators (Figure 21, four ellipses). The voice coil actuator was placed inside at the center of the device while two of the vibration motor actuators were fixed on the left side of the device and the other two on the right side of the device. Three different sensors - three ADXRS300 gyroscopes, four force sensitive resistors and a custom built 15-channel capacitive touchpad were used for input. An experiment, aiming to gather subjective experiences and evaluation of input and output, was conducted with the device without any interpersonal interaction among participants. In six blocks (3 input methods x 2 output methods) four different communication scenarios were presented to

evaluate input (moving, stroking and squeezing) and output (using one and four actuators). Four scenarios were expressing excitement after meeting a new person, agreeing with a message, alerting a friend who is speaking in a lecture and sending a haptic love message. As a result, the researchers found that squeezing and stroking was the preferred input methods. In terms of output four actuators were preferred to one actuator. Also duration of message was a notable parameter which was not dependent on input or output methods.



Figure 21: The haptic device on a tabletop (on the left) and upside down (on the right) showing the five actuator location [Rantala et al., 2011b]

In this part, three studies on haptic patterns were introduced. In the first paper by McDaniel et al. [2009] different haptic patterns were created using rhythm and pauses, while in the second paper, Rantala et al. [2011a] created three kinds of haptic patterns that were either positional (point oriented), linear (line oriented) or circular. In the last paper [Rantala et al., 2011b], three patterns-like-feeling for moving, stroking and squeezing were experienced. These studies show that effectiveness of pattern is not dependent on use of multiple actuators; rather relevance to incidence (such as frequency rate) is more valuable.

### 4.3 Haptics in Navigation

Navigational tasks with map in mobile phone have become easier. Due to the more immersive experience, haptically enabled mobile phone enables more diverse application concepts. Presently, using haptics researchers have attempted to create interfaces that would allow persons, who are visually, aurally or situationally impaired, perform these navigational tasks. Haptic feedback to convey GPS or other navigation data has commonly been presented to torso using a belt with vibro-tactile actuators. Other means are also available, and these are reviewed in this Section.

Boll et al. [2011] proposed a car navigation system using a vibro-tactile waist belt which provided navigation information to the driver. In prototype device, they used eight mobile phone vibration motors (Samsung SGH A400), affixed to the belt at a distance of 45 degrees around the waist (Figure 22). The setup of eight vibrators was derived from their previous study on pedestrian navigation. Using parameters such as rhythm, vibration and body location the researchers controlled the haptic information and display accordingly through actuators in belt to guide a driver in navigation. Like

conventional navigation system in the proposed device distance and direction were provided to driver. For turning, the direction was indicated by respective actuator. To indicate more accurate direction for example, the direction between front and front left, both actuators vibrated simultaneously. When indicating a turnabout, the eight actuators vibrated counter-clockwise for one second. The feedback about turnabout was informed to driver with changing rhythm, and duration. Four categories of distances (indicating distance from turnabout to driver's current position), "very far", "far", "near" and "turn now" were advised to driver with four, three, two, one pulse vibration respectively. Unlike conventional verbal navigator, at three locations the navigational commands are displayed to driver - before a turnabout, just entering turnabout and inside a turnabout (Figure 23). Before entering turnabout and inside a turnabout, the corresponding actuators with vibration feedback show the exit. The researchers arranged a pilot study and they found that tactile display was convenient for showing different directions.

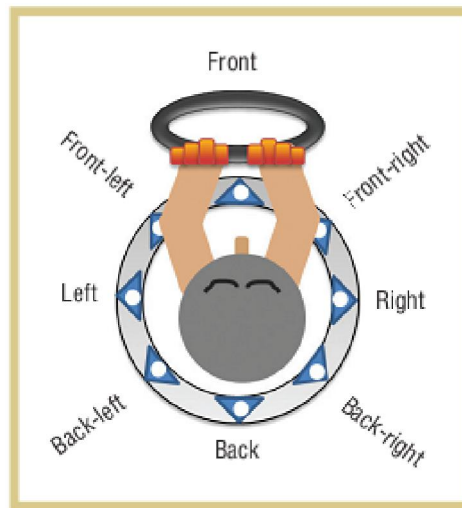


Figure 22: The tactile belt and a schematic of the tactile display [Boll et al., 2011]

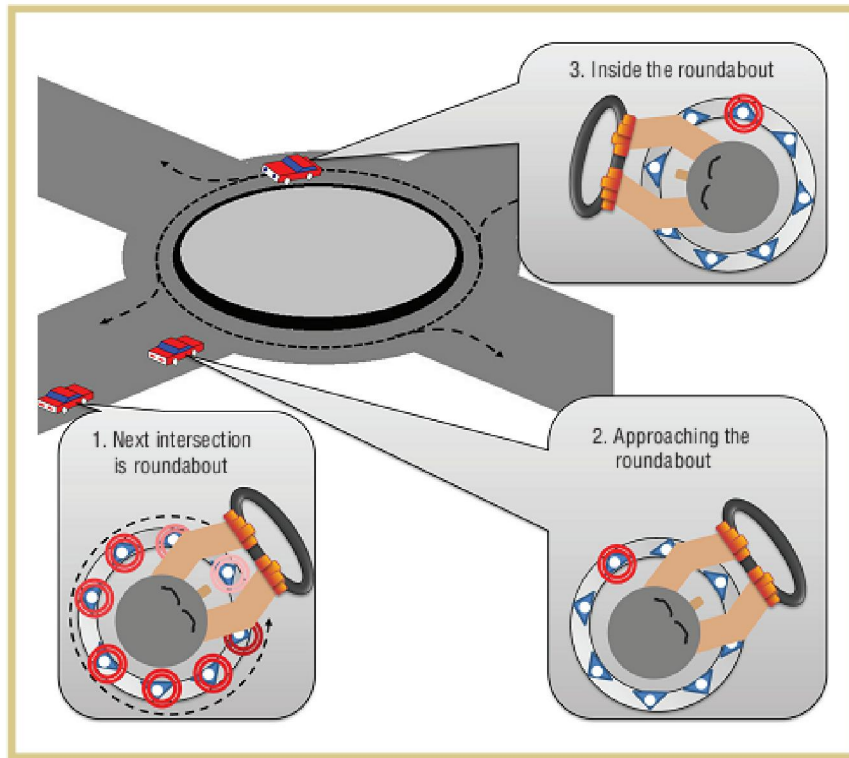


Figure 23: Roundabout presentation with the tactile belt. In step 1, eight vibrators activate one by one in a counterclockwise direction to indicate the roundabout ahead. In step 2, the left vibrator indicates the desired exit to take. In step 3, one pulse on the right side of the tactile belt informs the driver to exit now from roundabout [Boll et al., 2011]

Yang et al. [2010] designed a vibro-tactile display pad for a handheld mobile device. In this device, spatial and directional information were displayed employing sensory illusions of sensory saltation and phantom sensation. Sensory saltation is an illusion which is felt along intermediary points when consecutive stimulations are generated at two or more body locations. Phantom sensation is formed from two simultaneous equally loud stimuli. The prototype, named as T-mobile, comprised of twelve vibro-tactile panels. The prototype had a tactile surface containing twelve panels in 3x4 array arrangement (Figure 24). Two experiments were conducted for evaluating the prototype in creating directional and spatial information. In the first experiment for directional information, ten directional cues (Figure 25) are presented and the participants were to identify these directional cues on finger and palm. The result showed that the mean rate of identifying directional cues is 92.1%. According to result, success rate of 100% was achieved when vibration was felt on back of palm instead of finger and palm. In the second experiment, the goal was measuring perception ability of spatial information on different parts of hand. In this experiment, three actuators on the equator of T-Mobile were used for displaying vibration to nine spatial locations (Figure 26). Participants in this experiment answered as to which location stimuli were



presented. The result showed that locations 1, 5 and 9 where the actuators were directly attached were very distinctive whereas the other locations were less distinctive.



Figure 24: Vibro-tactile pad device, the T-Mobile [Yang et al., 2010]

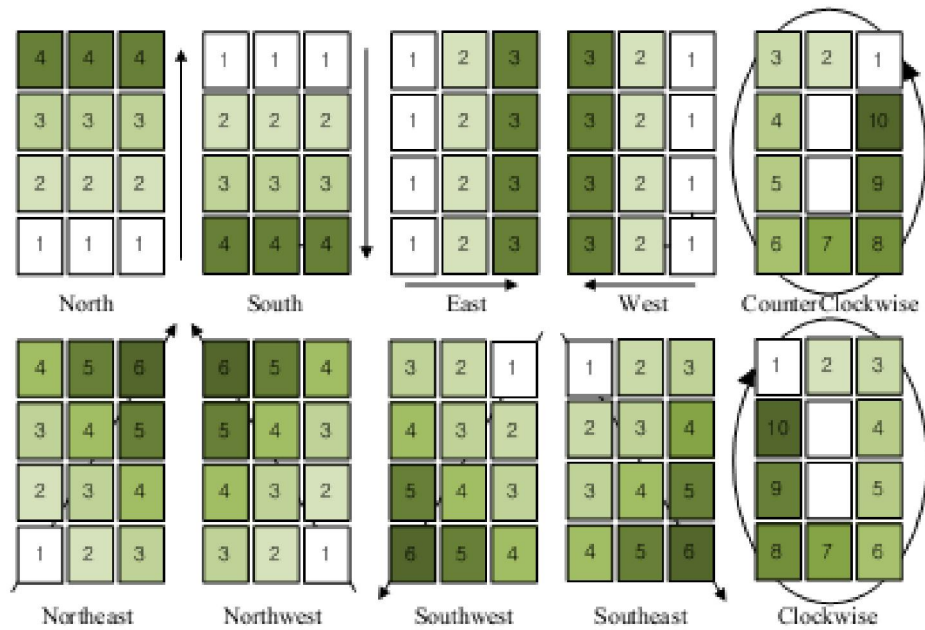


Figure 25: Representation of directional information [Yang et al., 2010]

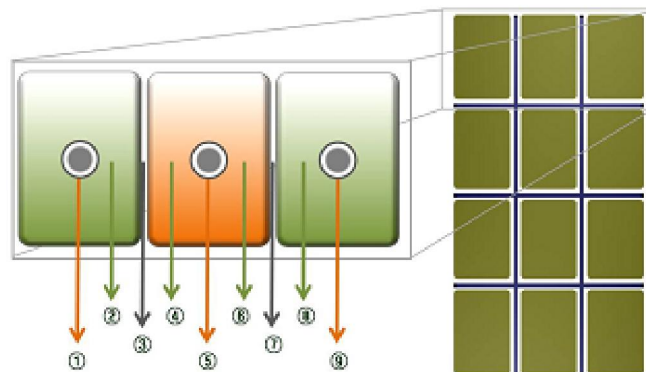


Figure 26: Schematic diagram of presenting nine-directions using three actuators [Yang et al., 2010]

Song and Yang [2010], studying cane usage behavior of visually impaired persons, suggested an interface, named as Haptic Sight (Figure 27), which could assist a visually impaired person to navigate his way to a destination. The interface was designed for indoor movement and could provide information about fifteen meters ahead of a person. Haptic Sight shown in Figure 28 would consist of 30x50 small blocks, built of double-acting cylinders and direction control valves. All these blocks could express space information with two layers - upper layer and lower layer. Space difference between these layers would compose different building entities such as doors, humps, obstacles, elevators and stairs (Figure 29). However, only a concept of Haptic Sight was introduced and, thus, no prototype or user study was presented.



Figure 27: the concept of Haptic Sight [Song and Yang, 2010]

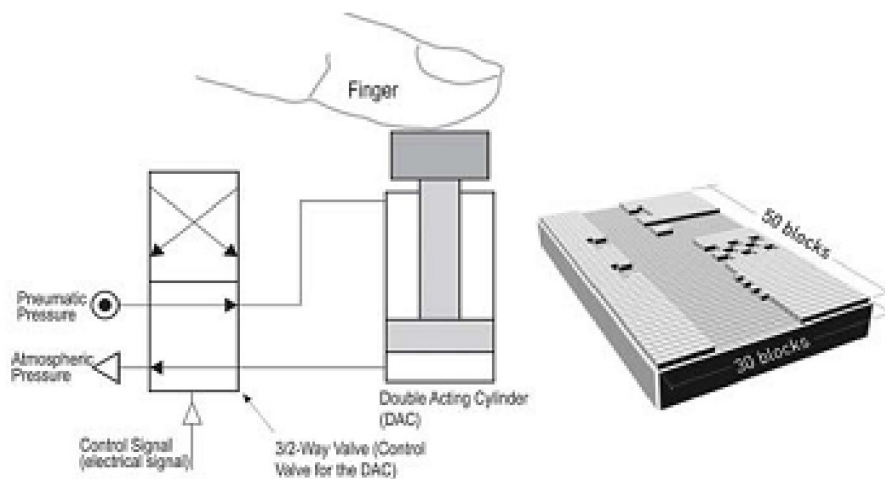


Figure 28: Basic structure of Haptic Sight [Song and Yang, 2010]

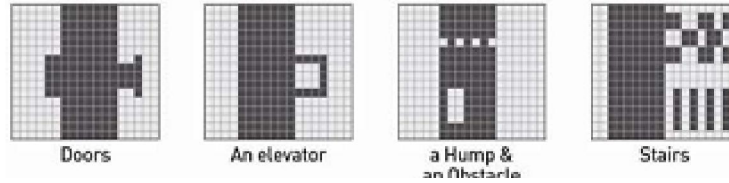


Figure 29: Building entities displayed on Haptic Sight [Song and Yang, 2010]

Here, three research papers were studied to learn about the haptic stimulation used in navigation. A car navigation system using a vibro-tactile waist belt [Boll et al., 2011] and a vibro-tactile display pad on a hand held mobile device [Yang et al., 2010] were discussed while these researches were designed for sighted persons who are engaged in other work. The third study, Haptic Sight [Song and Yang, 2010], has not been implemented yet but aimed to be developed in a mobile device for guiding visually impaired persons.

#### 4.4 Summary

In this Chapter, we presented previous studies on using haptics for interpersonal communication, presenting haptic patterns and navigations. Exploring haptics in mobile devices for interpersonal communication has given us the perception on haptic advancement; the haptic interaction through use of prototypes or devices still cannot be used as a metaphor for real life tactile interaction. We studied prototypes which try to create realistic haptic feedback by creating specific haptic patterns and consequently diversify haptic interactions. Our review showed that some patterns can still be improved. With the use of haptic patterns along with different prototypes, the research on haptics in navigation opened a new direction to research. Most of the haptic-navigation applications are for exploring the route towards the destination and the applications are designed for persons whose aural and visual senses might be busy with performing another task.

## 5. Methods in Spatial Data Presentation

Spatial data is the geographic information which is calculated with geographic coordinates system and topology. This kind of data assists to identify the geographic location. At present, one popular way to use spatial data with hand-held devices such as mobile phones is to tag photographs, text and other media with one's geographic location and then share it with the assistance of web-based mapping interface. However, the primary use of spatial data has been navigation. With the present navigation device systems, users receive the visual feedback that shows the direction on a display screen, while the audio feedback informs of changes of direction. These devices can also convey distance, direction and other related information via both the visual and audio feedback. In this Chapter we discuss the possibility of including the haptic feedback method to navigation applications.

### 5.1 Dynamic Haptic Feedback

The haptic feedback can be felt with the sense of touch through, for example, vibration forces. Many applications in tele-robotics, medical simulation, flight simulation, and rehabilitation robotics, generate force feedback. The force in some part of these devices such as lever or scissor is applied to restrict movement of those parts in specified space. Here the force is mostly discontinuous and hard which means the change of force after the restricted place is sudden and acute, and no intermediary intensity level of force is active amidst these two regions. Another kind of haptic feedback is tactile which is seen in mobile phone devices, controls in video games and other similar interaction devices. These commercial devices also mostly produce plain vibration where frequency and amplitude of vibration is static. The vibrations are used to convey simple information such as call alert, text type and explosion feedback. With this static type of haptic feedback the information can convey binary information (i.e. "yes" or "no"). This vibration cannot carry information with quality variance. That is, such feedback cannot be used to answer "how much" or "how large".

Dynamic haptic feedback can be defined as a concept of haptic feedback in which haptic property changes dynamically according to physical feature in the environment. Dynamic haptic stimuli characterize the constant change, activity, or progress of active stimuli in environment. The properties of haptic feedback can be controlled by changing its spatial and temporal properties [Nesbitt, 2005].

Dynamic change of the graphics property can be observed in a visually animated graphics. For reading the haptic information of this visual content Lévesque et al. [2012] used a haptic display where 4 mm lines, 4 mm discs and 15 mm of space were used to demonstrate the arrangement of a concert hall in a picture. From determining spatial possession of these objects on the haptic display, user can experience the tactile image. Similarly, in STReSS2 display [Wang and Hayward, 2009] a haptic device used for presenting a virtual tactile graphics. In this display, the tip of actuators deflected aside

from left to right and vice versa, and through lateral deformation the device produced tactile sensations on the finger-pad skin. Therefore, spatial properties may include spatial structure alias as pattern type (with pin matrices or solid objects of different shapes such as line, circle, rectangle), and area and dimension of the space (for example, length, width, slope, curvature) on which haptic feedback is presented.

Temporal properties consist of events that happen during presentation of haptic sensations in haptic display. In a study, Ferris et al. [2009] designed a tacton to show a vehicle driver the unobstructed lane for safe driving. The device was used to define two 900 ms presentation segments which were separated by 450 ms of off-time. Each 900 ms segment consisted of one to four pulses with 100 ms off time between each pulse. For example, the haptic device presented temporal haptic properties using event pulse displaying at specified time. In another research [Menelas and Otis, 2012], based upon variation of frequency intensity, six different kinds of tactons were designed in their experiment. Frequency is regarded as a temporal property because it relates the event with time. Thus, temporal properties may include temporal structure of haptic feedback such as intensity change where feedback frequency changes over time.

In this research, the spatial property of information is mapped to pattern of haptic feedback and the temporal property is mapped to frequency of haptic feedback. By varying these haptic properties it is possible to create different feedback combinations so that each feedback could express different information at different specified times. Thus, dynamic haptic feedback can enhance the quality of haptic feedback and improve the richness in haptic sensations.

## **5.2 Investigating Presentation of Spatial Data on Palm with Dynamic Haptic Feedback**

Static and discontinuous haptic feedback cannot properly present dynamic navigation data. Dynamic haptic feedback, on the other hand, could be adjusted to the changes in navigational data (e.g. direction and distance). Considering discussion on the dynamic haptic feedback property in the earlier Section 5.1, dynamic haptic data can be displayed with pattern-based and frequency-based haptic feedback. Navigation data with constantly changing nature can also be displayed with these two kinds of feedback.

As discussed in the Section 4.3, dynamic haptic feedback was displayed with a torso-based wearable system to convey the change of direction and distance to the user in a car environment [Boll et al., 2011]. In this research, rhythm and duration encoded haptic feedback was used for displaying the information, because in another research conducted by Asif et al. [2010] it was found that for a torso based wearable device “rhythm and duration encoded” haptic feedback is more reliable than “rhythm and intensity encoded” haptic feedback. Here, “rhythm encoded” haptic feedback is analogous to frequency feedback, because changing rhythm made changes in frequency.

The torso-based belt was appropriate for wearing around waist, but not appropriate for other parts of the body such as palm.

At present, mobile phone is one of the most commonly used hand-held devices. With rapid advancement of software and hardware mobile phones become more intelligent day by day. Gradually, different services are being included in today's mobile phones. Consequently, telecommunication standards organization has incorporated the new location technologies into the standards for mobile phones. Most commonly used methods for location technologies are satellite-based and cellular network-based technologies. Location information can also be derived from sensors, RFID, Bluetooth, WiMax, and Wireless LANs [Rashid et al., 2008]. Therefore, mobile phones can be good use for different location based services. However, mobile phones need more advancement in the use of haptic technology while this research specifically focuses on haptic interface. On the contrary, mobile device can be built with custom haptic technology. That is why in this research we work with hand-held mobile device instead of mobile phone.

Mobile devices are mostly held on palm and palm is one of the highly sensitive body parts for sensing the haptic stimuli [Myles and Binseel, 2007]. However, one limitation of the palm is its small receptive area. As we discussed earlier in the chapter two, in the palm area the skin is of glabrous type where RA (rapidly adapting) mechanoreceptors, that are Merkel's disks and Meissner's corpuscles, are active. Therefore, to stimulate properly in a palm area the organization of actuators and their contact points need to be placed at safe distance from each other. Furthermore, the stimulation frequency range of the actuator needs to be kept below 100 Hz because of the sensitivity range of the responsible mechanoreceptors for haptic stimulus detection. Thus, the design of the haptic stimuli to be applied to the palm can be different from those applied to torso.

Present study evaluates usage of haptics on the palm with a hand-held device and analyzes effectiveness and accuracy of the device in displaying the haptic information to a user. Here, we investigate alternative ways to encode the haptic information through an experiment seeking answers to the following questions, (a) Pattern change or frequency change - which one is more effective for conveying haptic information on palm? (b) Does the environmental noise affect the understanding of the haptic information?

### 5.3 Summary

In this Chapter, we have developed a concept of dynamic haptic feedback, introduced two different dynamic haptic feedback generation processes: pattern-based haptic sensation and frequency-based haptic sensation. Adoption of these haptic processes has been discussed in displaying spatial data on the palm. The goals of the experiment are presented with a hand-held device which is not a mobile phone device. We have

analyzed here that custom haptic technology integrated in the mobile device is more appropriate for using in experiment than that of the mobile phone device.

## 6. User Study

A user study was conducted for evaluating the effectiveness of dynamic haptic feedback for displaying spatial data. In the user study, haptic recognition was evaluated for presenting spatial data where recognition accuracy was the center of interest. Importantly, we did not use any resource for determining spatial data. For the purpose of user study, we predetermined spatial data (e.g. direction and distance) on our own and used spatial data using randomization method.

### 6.1 Participants

A total of eight participants, containing equal number of males and females, voluntarily took part in the experiment. Their mean age was 25 years and age range was 20-34 years. All participants were students in the University of Tampere or in other educational institutes. All participants had prior experience with haptics using mobile phones and some participants had experience with the haptic feedback using video game controllers. Prior to the actual experiment a pilot user of age 20 assisted in determining and fixing different experimental issues. This pilot user did not participate in the final experiment.

### 6.2 Apparatus Description

A hand-held device designed to be placed on palm was used in this experiment. This device was originally introduced in a study by Rantala et al. [2011a] which was earlier discussed in Chapter four. The device was designed to stimulate particular mechanoreceptors. To serve this purpose as described earlier four linear DC motors (LVCM-013-013-02 from MotiCont) were used as actuators in the device. The number of the actuators is four because with this arrangement it was possible to indicate directions. Further, this particular actuator was selected for its capacity to produce the strong feedback and the sufficient stroke length of 6.4 mm. The actuator has two parts which are magnetic housing and coil. Diameter and height of the actuator are 13 mm and 20 mm respectively. A pin with dimension of 3.18 x 15 mm (diameter x length) is fixed at the bottom of magnetic housing of each actuator. These pins get direct contact with palm skin through holes in the semi-spherical bottom of the device. The top of the device is covered with transparent lid which holds the coil of the actuator so that during actuation the actuator remains still.

During placing the device on the palm, the tip of the pin needs to have direct contact with skin. When the actuator starts to move, the body of the device stays still and only the actuated pin can be felt to touch the skin of the palm. The distance between four pins is 30 mm so that two points discrimination can be avoided. Importantly, actuators in the device are arranged in a balanced square form so that arrangement order can properly replicate the idea of the direction. Actuators are controlled with audio signals and in order to generate audio signal Pure Data (PD) audio synthesizer software is used. The



produced audio signal then needs to be amplified which is done by connecting two external Gigaport sound cards between the device and the computer. Finally, the amplified audio signal is strong enough to move the actuators.

### 6.3 Design and Stimuli

The experiment was organized in two test conditions that were feedback mode and environmental mode. Feedback modes are pattern-based haptic feedback and frequency-based haptic feedback while environmental modes are noisy and noise-free environment. Therefore, four different combinations of test conditions were a) pattern-based feedback in noise-free environment, b) pattern-based feedback with noise, c) frequency-based feedback in noise-free environment and d) frequency-based feedback with noise. All these combinations were presented to each user. In the experiment, the modes were varied to display 24 different stimulations combination of eight directions and three distances. Each stimulus contains a direction and a distance, and shows them in a simultaneous manner or at a tiny interval.

Among eight directions, four directions are linear (i.e. forward, backward, left and right) and the other four are diagonal (i.e. forward-left, forward-right, backward-left and backward-right). In this research, the range of data is adopted instead of any specific distance, because representing haptic data for a specific distance can be plentiful information in the context of present research. For the experiment, the range of distance may be thought of into three ranges such as one to five kilometers, six to ten kilometers and eleven to fifteen kilometers which alternatively may be expressed as “close”, “near” and “far”. Thus, with presenting the small amount of haptic data, it can be easier for user to recognize the range of the distance with the haptic feedback.

Eight directions are shown through the device on palm with its four actuators (Figure 30). When the direction “forward” is indicated, both the actuators near one’s fingers (top actuators) shown in the Figure 30 are vibrated. When the direction “left forward”, the top-left actuator vibrates (Figure 30). When the pattern-based haptic feedback is selected, at first the direction is haptically displayed and after completion of the direction display distances are expressed with one, two or three circular sensations. The circular sensations are created with the vibration of four actuators one after another in circular way. When one circular motion is felt, all pins or actuators vibrate once in a circular fashion; in case of two and three circular motions, one circular motion will be repeated two or three times. In Figure 31, the vibration sequence in the actuators for “forward-left + one circular motion”, “forward-left + two circular motions” and “forward-left + three circular motions” are shown. In the leftmost arrangement of Figure 31, numerical value of 1, 2, 3, 4 and 5 indicate sequence of pins vibration that is followed by creating vibration to display “forward-left + one circular motion”. Further, in case of frequency-based haptic feedback, direction information and distance information are concurrently displayed with the vibration. The distance information is

varied with three different vibration frequencies that were 13 Hz, 30 Hz and 90 Hz. In Figure 32, the vibration sequence for “forward-left + low frequency”, “forward-left + middle frequency” and “forward-left + high frequency” are shown. Therefore, the difference between pattern-based haptic feedback and frequency-based haptic feedback is that in the pattern-based haptic feedback direction and distance are displayed one after another while in the frequency-based haptic feedback the direction is displayed with the corresponding distance frequency.

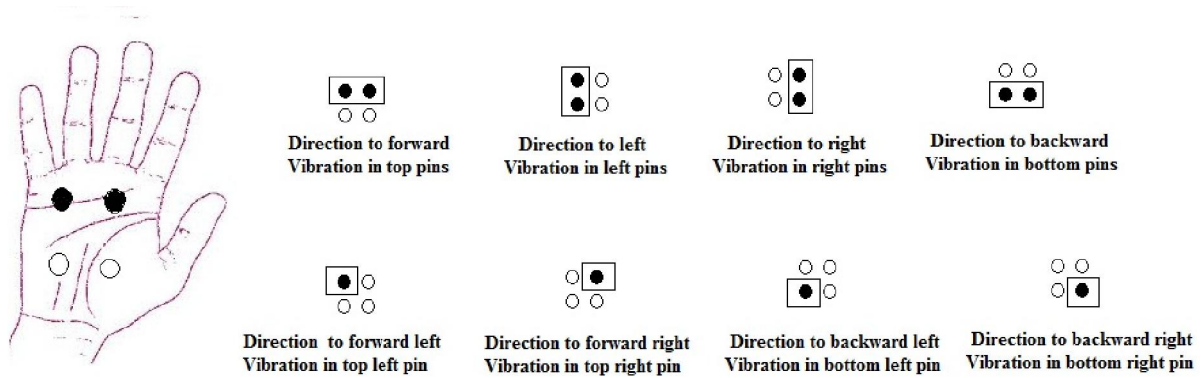


Figure 30: Placement of pins on palm and display of direction on the corresponding pins

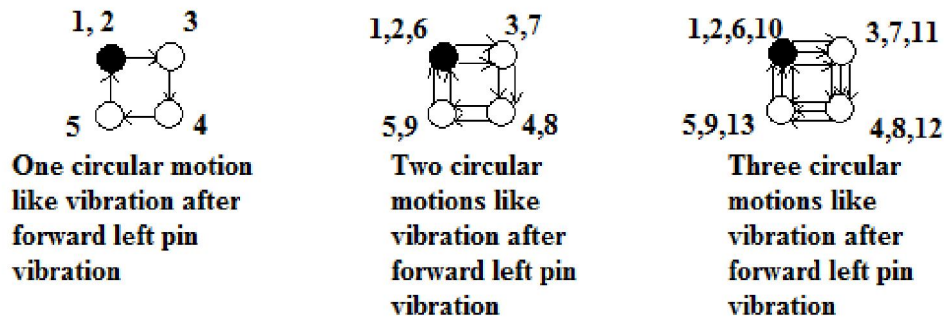


Figure 31: Display of distance with pattern

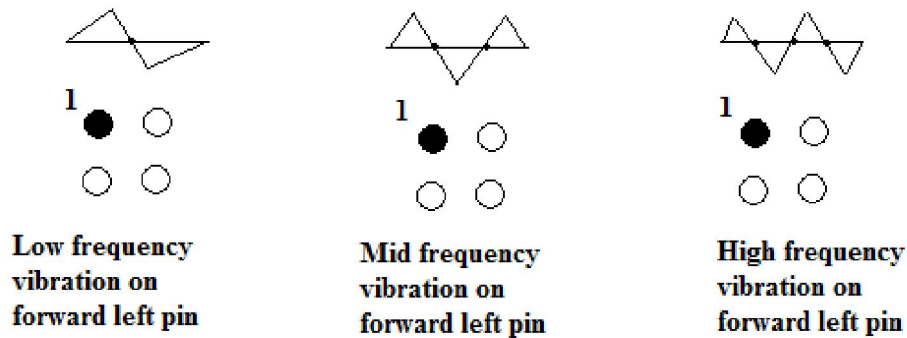


Figure 32: Display of distance with frequency

The frequency and the duration of haptic vibration in the whole experiment were selectively designed so that the vibration stimulation would be more explicit. The pilot user's experiences helped in designing the haptic vibration for the experiment. In pattern-based vibration, the duration of direction display was 1 second. After the delay of 1 second, the distance was displayed with the circular motion sensation; earlier (before pilot user's experience) the delay was half second. In a single circular motion, a full cycle of the circular sensation completed in 1.6 second and there was no delay between the vibrations of consecutive pins. However, there was a break of 0.4 second between two consecutive full circular sensations while the break was 1 second before the pilot user's experience. Further in the frequency-based vibration, distance and direction eventually displayed the haptic vibration which was 1 second long. The actuators were driven by an audio signal of 15 Hz sine wave and with an output power of 0.06 W; the amplitude of the sine wave was constant throughout the actuator activation.

#### **6.4 Procedure**

This was a within-subject experiment where all the participants completed all test conditions. In the beginning, participants were briefed about the aim and procedures of the experiment and introduced to the hand-held device. The concept of pattern change and frequency change in the device was also described. After this, participants were given some five to ten minutes time to learn and recognize the feedback in a practice session. In both practice and real test sessions the writer operated the designed haptic interface using the Pure Data program. The operator was giving stimuli one after another to the user who was holding the device on palm and user's task was to perceive and recognize the stimulation that was given on his/her palm. Then, participant's task was to verbally indicate the felt feedback (e.g. left-close, right-far, forward left-near, backward left, backward right). In the experiment, the participants were advised to hold the device on the palm so that all four actuator pins would get direct contact with the palm skin. Furthermore, they were advised not look at the device during the experiment for any visual feedback.

After the practice session, the real test session began. Every participant's answers were recorded using a spreadsheet by the operator. Every participant was provided a total of 96 stimuli (8 directions x 3 distance ranges x 2 feedback conditions x 2 environmental conditions) in four combinations from two test conditions. As we discussed already in the Section 6.3, four different combinations of test conditions were a) pattern-based feedback in noise-free environment, b) pattern-based feedback with noise, c) frequency-based feedback in noise-free environment and d) frequency-based feedback with noise. Therefore, the experiment for a participant was divided into four segments. In two segments every participant had to wear headphones that played noise audio for creating noisy environment to the user. The order of test segments was

balanced using the Latin square design. In the experiment participants sometimes experienced fatigue, and because of this a short break was taken between segments. At the end of the real test session, every participant was given a questionnaire with some open-ended and close-ended questions about the experiment. Thus, the whole experiment took about one hour for a participant. Twenty four different stimuli were repeatedly shown in four test conditions in different order to eight users of which every two users received stimuli in same order.

## 6.5 Results

Tables 7, 8, 9 and 10 describe the confusion matrices containing results for pattern-based and frequency-based stimuli in noisy and noise-free environment. In the matrices, directions are denoted with “B” for backward, “L” for left, “R” for right, “F” for forward and three distance ranges in case of pattern-based feedback (i.e. one to three circular motions) and frequency-based feedbacks (i.e. low, medium and high frequency) are presented with numerical values 1, 2 and 3 respectively. Errors in detecting direction from the presented stimuli are shown with “d” for direction and errors in detecting distance are shown with “p” for pattern and with “f” for frequency. Further, “dp” or “df” mean both the direction and the distance (pattern or frequency) are mistaken. Thus, “1d” means the number of errors in detecting the direction of presented stimuli is 1 and “2dp” means the number of errors in detecting both the directions and the distance ranges is 2. In the diagonally arranged squares from the top left corner to the bottom right corner of the matrices correct numbers of the detection are shown. The right-most column of numbers shows the number of presentations for every stimulus to all users. The bottom-most row of numbers shows the number of user’s responses for a particular stimulus of which all responses might not be correct; so this number shows both correct and incorrect trials in response.

Table 7: Confusion matrix for pattern-based haptic stimuli in the noise-free environment

		User Response																													
		B1	B2	B3	BL1	BL2	BL3	BR1	BR2	BR3	L1	L2	L3	R1	R2	R3	F1	F2	F3	FL1	FL2	FL3	FR1	FR2	FR3						
Presented Stimulus	B1	6			1d			1d																					8		
	B2		7										1dp																8		
	B3			8																									8		
	BL1				7							1d																	8		
	BL2					8																							8		
	BL3						8																						8		
	BR1							8																					8		
	BR2								8																				8		
	BR3									8																			8		
	L1										1d		1p	6															8		
	L2											8																	8		
	L3												7										1d						8		
	R1													7														1d	8		
	R2															5													8		
	R3																7												1d	8	
	F1																	7												8	
	F2																		6											8	
	F3																			7										1d	8
	FL1																				8									8	
	FL2																					8								8	
	FL3																						8							8	
	FR1																							8						8	
	FR2																								8					8	
	FR3																									8				8	
		6	7	8	8	8	9	9	12	6	9	7	8	7	5	7	7	6	7	9	11	8	9	8	11			192			

Table 8: Confusion matrix for pattern-based haptic stimuli in the noisy environment

		User Response																											
		B1	B2	B3	BL1	BL2	BL3	BR1	BR2	BR3	L1	L2	L3	R1	R2	R3	F1	F2	F3	FL1	FL2	FL3	FR1	FR2	FR3				
Presented Stimulus	B1	8																									8		
	B2		7					1d																			8		
	B3			8																							8		
	BL1				8																						8		
	BL2					8																					8		
	BL3			1d			7																				8		
	BR1							7	1p																		8		
	BR2								8																		8		
	BR3									7																1d	8		
	L1										6			1d						1d							8		
	L2											8															8		
	L3												7										1d				8		
	R1													7										1d			8		
	R2														7										1d		8		
	R3															8											8		
	F1																8										8		
	F2																	8									8		
	F3																		8								8		
	FL1																			8							8		
	FL2																				8						8		
	FL3																					1p	7				8		
	FR1																							8			8		
	FR2																								8		8		
	FR3																									8	8		
		8	7	9	8	8	7	7	10	7	6	8	7	8	7	8	8	8	8	9	9	8	9	9	9		192		

Table 9: Confusion matrix for frequency-based haptic stimuli in the noise-free environment

		User Response																											
		B1	B2	B3	BL1	BL2	BL3	BR1	BR2	BR3	L1	L2	L3	R1	R2	R3	F1	F2	F3	FL1	FL2	FL3	FR1	FR2	FR3				
Presented Stimulus	B1	6	1f		1d																							8	
	B2		6			2d																						8	
	B3		1f	4			1d			2d																		8	
	BL1				7	1f																						8	
	BL2				1f	7																						8	
	BL3						8																					8	
	BR1							7	1f																			8	
	BR2							1f		7																		8	
	BR3										8																	8	
	L1				1d							6									1d							8	
	L2					1d							6			1d												8	
	L3						2d							4								1df	1d					8	
	R1							1d							4	2f								1d				8	
	R2											1d				6									1d			8	
	R3								1df	1d							6											8	
	F1																	4	2f					2d				8	
	F2								1d										6						1d			8	
	F3																			4						1df	1d	8	
	FL1																				7	1f						8	
	FL2																				1f		6	1f				8	
	FL3																						8					8	
	FR1																							8				8	
	FR2																							1f	7			8	
	FR3																										8	8	
		6	8	4	10	11	11	9	10	11	6	7	4	4	9	6	4	8	4	9	8	12	12	10	9	192			

Table 10: Confusion metric for frequency-based haptic stimuli in the noisy environment

		User Response																											
		B1	B2	B3	BL1	BL2	BL3	BR1	BR2	BR3	L1	L2	L3	R1	R2	R3	F1	F2	F3	FL1	FL2	FL3	FR1	FR2	FR3				
Presented Stimulus	B1	5	1f		1d								1d															8	
	B2		8																									8	
	B3			5			1d			2d																		8	
	BL1				6	2f																					8		
	BL2				1f	7																					8		
	BL3			1d			6						1d														8		
	BR1							8																			8		
	BR2							1f	6						1d												8		
	BR3									8																	8		
	L1										6										1d	1df					8		
	L2										1f	7															8		
	L3												6														8		
	R1													5	1f									2d			8		
	R2														8												8		
	R3									3d							2										3d	8	
	F1																	6	1f		1d						8		
	F2																		8								8		
	F3																			4						1d	8		
	FL1																				8						8		
	FL2																		1d		1f	6					8		
	FL3																					1f	7				8		
	FR1														1df									5	2f		8		
	FR2																							2f	5	1f	8		
	FR3																									8	8		
		5	9	6	8	9	7	9	6	13	7	7	7	6	11	2	6	10	4	11	8	12	9	7	13	192			

In total, the haptic recognition rate considering both the pattern-based and frequency-based recognition was 85.5%. Combining noisy and noise free conditions, the pattern-based response accuracy rate was 93% and the frequency-based response accuracy rate was 78.1% (Figure 33). Mean response accuracy rates for the pattern-based stimulus recognition in the noise-free environment and in the noisy environment were 91.1 and 94.8% respectively (Figure 34). Mean response accuracy rates for the frequency-based stimulus recognition in the noise-free environment and the noisy environment were 78.1 and 78.1% respectively (Figure 34).

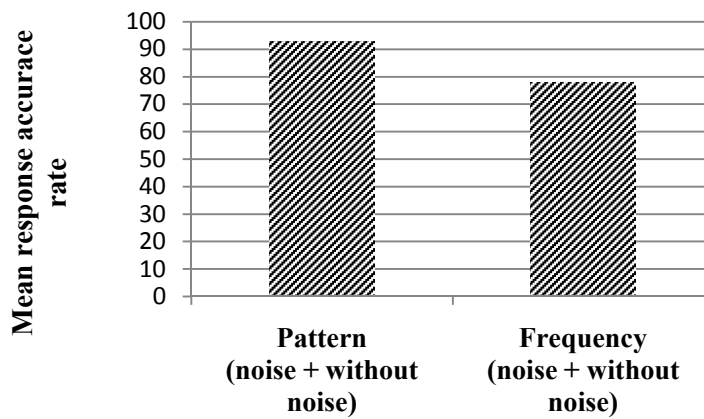


Figure 33: Mean response accuracy rate in the pattern-based and frequency-based conditions

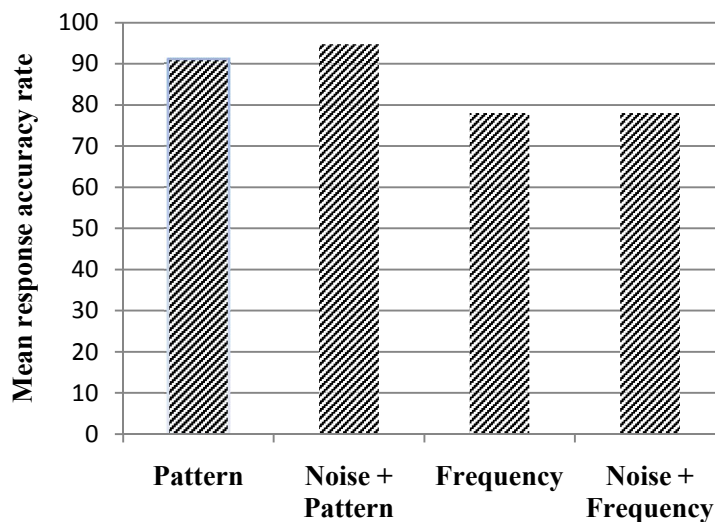


Figure 34: Mean response accuracy rate in different conditions

From the Tables 7, 8, 9 and 10 we see that the single pin vibrations (for example, forward-left, forward-right, backward-left and backward-right) were more error-prone than the double pins vibrations (for example forward, backward, left or right). In

displaying the direction, mean error rates in the single pin vibration and the double pins vibration were 17.4 and 3.1% respectively when both the pattern-based stimuli and the frequency-based stimuli are considered (Figure 35). Similarly, vibrations of the single pin and the double pins were present in the frequency-based distance. During the presentation of frequency-based distance stimuli, mean error rates for the single pin and the double pins were 12 and 5.7% respectively (Figure 36).

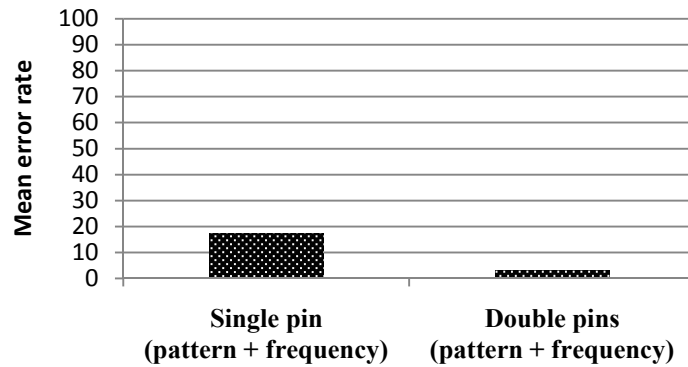


Figure 35: Mean error rate in the direction

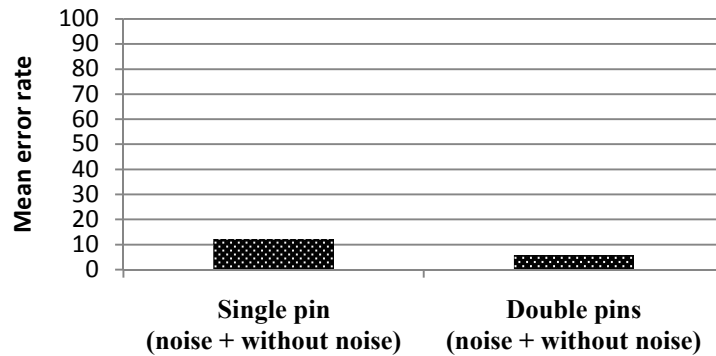


Figure 36: Mean error rate in the frequency-based distance

From the experiment it is noticeable (in Figure 37) that the mean error rate (2.1%) in the pattern-based distance stimulation was smaller than the mean error rate in the frequency-based distance stimulation (17.7%). However, there was no difference in mean error rates for the pattern in circular motions. Figure 38 shows that mean error rates in detecting different patterns which were 4.7% for all patterns. Furthermore, mean error rates for the low, medium and high frequency were 15.6, 11.5 and 16.7% respectively (Figure 39).



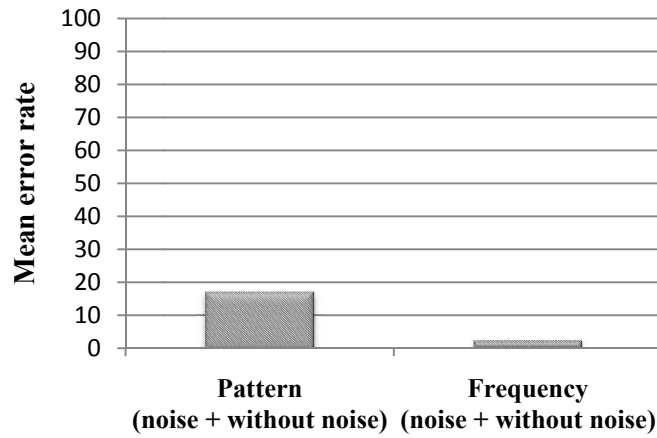


Figure 37: Mean error rate in the distance stimulation

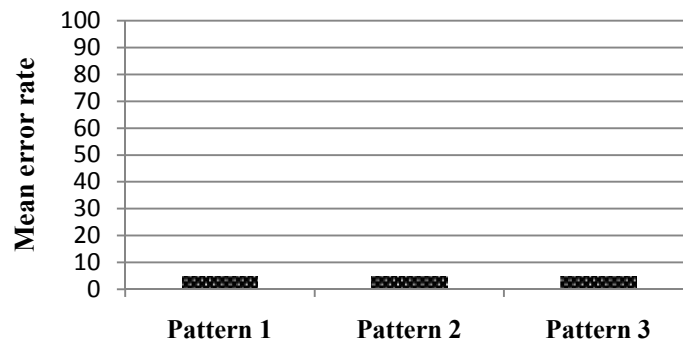


Figure 38: Mean error rate in the pattern-based distance stimulation

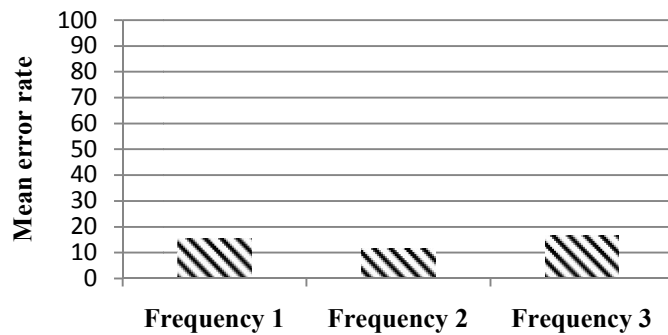


Figure 39: Mean error rate in the frequency-based distance stimulation

Figure 40 shows the mean error rate in individual user's performance. Individual user's performance greatly varied in the experiment and specifically in the recognition of the direction and the frequency-based distance, the variation is noticeable.

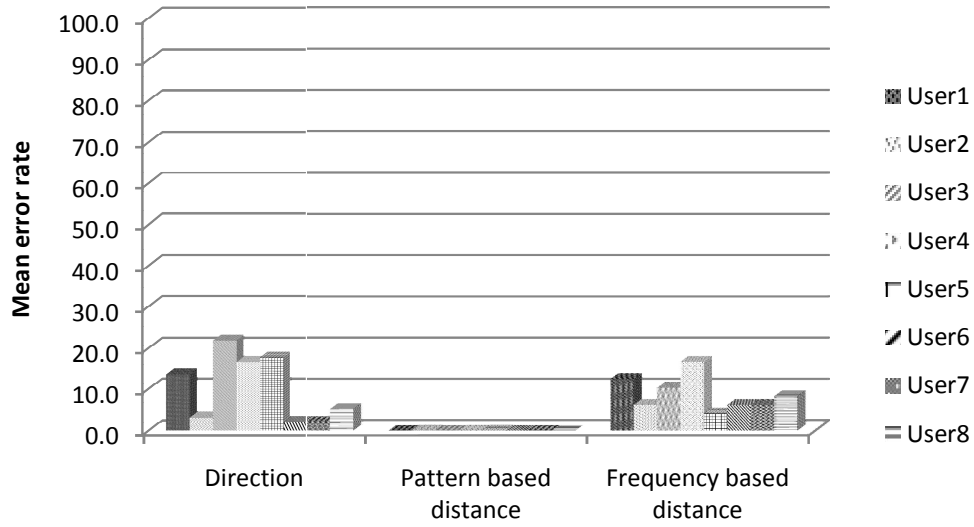


Figure 40: Mean error rate in the navigation data

## 6.6 Summary

In the chapter, we discussed the experiment including participants, apparatus, stimulus design, experiment process and outcome of experiment analysis. In the result, the recognition rate of haptic sensation was 85.5%, when in recognition of haptic feedback pattern based response was more successful than frequency based response. Further, noisy and noise free environment had different effect on recognition results of haptic sensation.

## 7. Discussion

In the user study, two kinds of haptic feedback, pattern-based feedback and frequency-based feedback were shown to user and users preferred the pattern-based feedback. In their comments, they expressed that pattern-based haptic feedback was more explicit in terms of the quality of display as compared to frequency-based haptic feedback. In addition, a user commented that it was easy to recognize patterns. Thus, the result provides new understanding in relation to the findings in an earlier research [Asif et al., 2010] where only different frequency-based feedbacks are compared, and “rhythm based and duration based feedback” was found to be the most preferred haptic feedback. Asif et al. [2010] did not include pattern based feedback (such as only “intensity based feedback” or “duration based feedback”) for comparison.

During pattern-based distance error, error rates in three individual distances were the same. However, with circular motion it took more time to display the distance data. In the user study, during the circular motion all pins vibrated consecutively in a circular way. When the first two pins vibrated in this way, a user could already recognize a circular motion. Then, he or she waited for completing vibrations in last two pins. At that time, the circular motion may feel monotonous and sometimes the users lost their concentration. As a consequence, a user may forget to count the number of circular motion patterns. To resolve the monotonicity or arising hesitation from losing concentration two measures can be taken. Firstly, it is possible to shorten the circular motion time. Secondly, when there is more than one circular motion, the second or every other circular motion could be changed to the counter-clockwise motion.

In the frequency-based stimulation, three levels of frequencies were tested and among them the medium frequency was less error-prone. One user commented that the medium frequency was more quickly recognizable than the low or the high frequencies. Specifically, they felt that the low and high frequencies were sometimes confusing and hard to distinguish. The reason perhaps was in a low frequency when the pin touched to skin, it could be felt light and in a high frequency when the pin touched so quickly that it might also feel light; thus low and high frequencies might seem confusing to the user. Perhaps, the better selection of frequencies could resolve the confusion. However, the frequency sensation may vary greatly among individuals. Some users also would have preferred a custom selection of frequency.

In the post-experimental commentary, users also expressed their preference for the pattern-based stimulation display. However, as a whole, users liked the concept of using frequencies for representing different information. Interestingly, some users were able to detect the frequency differences reliably and, thus, had very few errors in detecting frequencies. Perhaps, individual experience or personalities sometimes affect the sensation of haptic stimuli.

Furthermore, double pins vibrations (for example, forward, backward, left or right) were found to be better recognizable than single pin vibrations (for example, forward-left, forward-right, backward-left or backward-right). Thus, fewer errors were found in the stimuli using the double pins than the stimuli using the single pins. The performance during the double pins recognition was better possibly due to intensification of the pins' location from the second pin. In case of any confusion arising from the single pin location, simultaneous vibration of the second pin assists to recognize the location more accurately.

In earlier research [Rantala et al., 2011a], single pin and double pins vibrations were not referred to as how these vibrations were referred to our experiment. However, it could be interesting if we note the linear stimuli (i.e. bottom-top, top-bottom, left-right, and right-left) recognition rates in the diamond configuration and the square configuration in that experiment. Single pin vibrations were more error prone than the double pins vibrations in the present research. However, in the research [Rantala et al., 2011a], error rates were very low for the positional stimuli (i.e. bottom, top, left, right) in both the diamond configuration and the square configuration, where single pins were used. In this case, our concept is if the double pins were used in displaying those positional stimuli, the error-rate could be the lowest in that research.

In this experiment, the hand-held device was held in such a way that all pins could touch skin. However, it was not comfortable to hold the device in a particular position for a long time and then, any pin's vibration and respective location could be missed. To address this issue it may be effective to design the stimulation in a unique way so that double pins or more pins would vibrate to display a single stimulation.

Further, with noise the mean accuracy rate was better than without noise. Previously, Rantala et al. [2011a] did not use additional noise sound for distraction. Instead, a noise cancelling headphone was used to block environmental audio. In contrast, in our experiment the same headphone was used to play additional noise to the user. The plain nature of the noise sound might help users to concentrate more on the feedback.

A research work done by Yang et al. [2010] was discussed in the Section 4.3. The aim of the user experiment in that research is very similar to the aim of the experiment in this thesis. Like the present thesis, in that research researchers measured the accuracy rate in presenting directional cues. However, their method of presenting haptic sensation was different from the presented method in this thesis. To present haptic sensation they used a concept of two illusions, sensory saltation and phantom sensation. In their first experiment of presenting directional cue, they used twelve vibro-tactile panels to present the directions and achieved 92% of means accuracy rate. On the other hand, with the present device in our experiment only four actuators used, and mean accuracy rate were achieved 88 and 94.3% in presenting directional information with single pin and double pins, respectively. Yang et al. [2010] used three vibro-tactile panels in

displaying spatial data. However, this concept of spatial data was not identical to the concept of distance data in this thesis. Yang et al. [2010] implemented the innovative concept of illusions, but higher accuracy rate was achieved with the simple implementation of four actuators' device in the experiment of this thesis.

Boll et al. [2011] used torso based wearable system where eight actuators were used in displaying direction and distance. This was worn around driver's waist, used for car navigation. Due to location in body for haptic sensation, direction in torso based system may be more comfortably detectable than the same in hand-held device. They arranged three separate experiments for displaying direction, distance and round-about haptically, and these separate results produced the limitation of the research to decide singly from different results. For example, in the first experiment of displaying direction, among four types of encodings "one vibrator distance design" was the most suitable where distance and direction encoded in a single feedback. However, in the third evaluation of presenting roundabout information, they found that only direction-based encoding was the most preferred encoding where only direction encoded in a single feedback. Thus, combined arrangement of all three experiments might result different which might be better comparable with present research result. However, considering the second experiment result, "duration and rhythm based encoding" (which may be analogous to frequency based haptic sensation in our present thesis) is the best encoding for displaying distance, we find that the result is opposite to our finding in the experiment. Perhaps, three reasons are responsible for making the difference in the results of two experiments. Firstly, mechanoreceptors in waist are more active than in palm. Secondly, two-point discrimination is higher in torso-based system than hand-held device. Thirdly, belt can be placed more perfectly around waist than hand-held device is placed on palm.

In the light of the result in our experiment, the palm is a body part where the pattern-based haptic feedback is more perfectly distinguishable and recognizable than the frequency-based feedback. However, with the cognitive load or distracting noise, the recognition of pattern difference might be difficult. Therefore, pattern-based stimulation should be designed in a proper manner so that users intuitively but correctly might remember the whole pattern if they miss some part of pattern. From the comparison between the results of our experiment and the results of the related researches, in a small area like palm and with a multi-actuator arrangement, direct contact of linear actuators with skin can be more effective. However, the number of actuators and the distance among the actuators should be carefully determined so that any actuator could not be superfluous and the haptic sensation could be sensed properly at the appropriate location on the palm. Thus, appropriate hand-held device and proper haptic stimulation can present spatial information and other relatively simpler information on the palm.

## 8. Conclusion

Most common modalities to interact with hand held devices or mobile devices are the visual feedback and the aural feedback. On the contrary, the haptic feedback has been prioritized less for a long time. However, in recent times the haptic feedback has gained popularity. Also in the present study, participants liked the haptic mode of stimulation and welcomed the haptic possibility of feedback in commonly used devices. They commented that “haptic” is a potentially preferable method for conveying the spatial information.

Here, through a user experiment we investigated a number of questions that were: (a) Pattern change or frequency change - which one is more effective for conveying the haptic information on palm? (b) Does the environmental noise affect the understanding of the haptic information? The answer to the first question is that people more likely selected pattern-based haptic feedback while the minimum error rate in this mode supports the users’ preference. The answer to the second question is that the environmental noise positively affects the understanding of haptic information. The second answer seems opposite to our perception prior to the experiment, which was that environmental noise may have a reverse effect on users’ performance. The reason of a different finding in the second answer may be for playing the continuous noise sound with headphones and perhaps some change in providing noise may show a different result. In this case, noise may be like a long conversation, or any meaningful audio.

The experiment pointed out some new problems or difficulties which were not our concern prior to the experiment. The first one is that many users felt fatigue in their hand and arm while holding the device because they had to keep their palm wide open for a long time. Some users suggested a different device shape which would be ergonomically more comfortable in the palm. Here, the question is if a more comfortable device allows better recognition of the haptic feedback variation and consequently, increases the performance rate of the haptic feedback. In the experiment, we discovered that the double pins’ vibration was more detectable than the single pin’s vibration. With respect to this finding, the question is if the increase in the number of actuators positively changes the recognition rate. To address this question, new device designs could be implemented. Another question is if changes in frequency-based feedback and in pattern-based feedback would increase the haptic recognition rate. To address this question, even a custom frequency and pattern setting can be added according to individual preferences. These are the potential questions that can make the experiment more realistic and on the other side, strengthen user’s capability to recognize the stimuli with fewer errors.

From the experiment, we realize that pattern-based haptic stimulation is more detectable than frequency-based haptic stimulation using our hand-held device on the palm. In the experimental result, the haptic recognition rate considering both pattern-

based and frequency-based recognition was 85.5% which gives us understanding that the haptic data display using the hand-held device is a prospective study and also, the haptic feedback can be used more effectively in navigation. Route map, searching new place on the map, driving guide can be potential features using the haptic navigation system which haptically can present the data, and would also let user to involve in multitask. Also, a visually impaired person could use this kind of system for navigation. Further, the accurate haptic feedback recognition on the palm from a handheld mobile device could enhance the quality of the device which can be used even for the complex interpersonal communication. In further continuation of this study, a hand-held mobile haptic system needs to be developed which is ergonomic to hold in hand and a user can accurately and precisely recognize the haptic stimulation displayed by the system.

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